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DEPARTMENT OF THE INTERIOR
UNITED STATES RECLAMATION SERVICE
IN COOPERATION WITH
THE STATE OF CALIFORNIA AND THE
IRON CANYON PROJECT ASSOCIATION

Report on Iron Canyon Project California

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By

HOMER J. GAULT.
Engineer, U. S. Reclamation Service
AND
W. F. McCLURE.
State Engineer of California

MAY, 1920.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1921

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REPORT ON IRON CANYON PROJECT.

The Iron Canyon project on the Sacramento River in California contemplates supplying water for irrigation of about 225,000 acres of land mainly situated between Red Bluff and the south line of Glenn County on the west side of the river. It has been the subject of a number of investigations and reports in the past, the latest up to the present time being by the United States Reclamation Service in 1914. At that time the investigations were carried out under a cooperative agreement between the Reclamation Service and the Iron Canyon Project Association. A very comprehensive report of these investigations was published, discussing the various features of the project, and containing also the report and recommendations of a board of review. Among other things a more complete investigation of the project was recommended.

The present work has been done in pursuance of the cooperative contract printed below, and may be considered as an extension of the work of 1914. As this report is supplementary to that of 1914 the data contained in the former report will not be repeated herein further than is necessary for a clear understanding of the present work.

COOPERATIVE CONTRACT.

This agreement, made this fifth day of May A. D., 1919, between the United States of America, by Franklin K. Lane, Secretary of the Interior, pursuant to the act of June 17, 1902 (32 Stat., 388), and acts amendatory thereof or supplementary thereto, the State of California, acting by and through the Department of Engineering of said State, and the Iron Canyon Project Association, of Red Bluff, California, a corporation organized under the act of March 21, 1905, of the State of California.

Witnesseth, that:

1. Whereas the parties hereto desire to have surveys and investigations made of the Iron Canyon project in the drainage area of Sacramento River, in the State of California.

2. Now, therefore, in consideration of the premises and the mutual covenants and agreements herein contained, it is stipulated and agreed between the parties hereto as follows:

3. The Secretary of the Interior, upon the execution of this contract, will make available for the work proposed herein the sum of five thousand dollars ($5,000.00), and also an additional sum of five thousand dollars ($5,000.00) after July 1, 1919, in case necessary appropriations for the purpose have been made by Congress, and corresponding amounts have been made available by the

other parties as hereinafter provided. The State Department of Engineering will make available, upon the approval of this contract, the sum of five thousand dollars ($5,000.00), and also an additional sum of five thousand dollars ($5,000.00), on or before July 10, 1919. The Iron Canyon Project Association will make available upon the execution of this contract the sum of five thousand dollars ($5,000.00), and also an additional sum of five thousand dollars ($5,000.00), on or before July 10, 1919. When the sum of five thousand dollars (5,000.00) to be provided by the State Department of Engineering has been made available and the Iron Canyon Project Association has placed the sum of five thousand dollars ($5,000.00) to the credit of the special fiscal agent of the United States Reclamation Service, at Orland, California, or such other officer as may be designated by the Director of the United States Reclamation Service, the work provided hereunder shall be promptly begun. On or before July 10, 1919, the Iron Canyon Project Association, upon notice from the United States Reclamation Service that the second sum of five thousand dollars ($5,000.00) of Federal funds has been made available, shall place to the credit of the said special fiscal agent the sum of five thousand dollars ($5,000.00), for continuing the work herein provided.

4. The investigations and surveys will be made in order to ascertain the feasibility of the Iron Canyon project, near Red Bluff; to outline its limits, character, and cost of development; to determine the ways and means whereby the public waters, natural lakes, if any, reservoir sites, State and public lands, and other resources may be used, reserved, and disposed of in connection with such irrigation project to the highest public advantage; also to determine what power may be developed as an incident to the construction of such irrigation project and the value and possible use thereof.

5. All surveys and investigations contemplated hereunder shall follow a general plan of operations agreed upon by the Reclamation Service, through its proper officers, the State Engineer of California, and the Iron Canyon Project Association, through its president.

6. The work hereunder shall be performed by the United States Reclamation Service and the State Department of Engineering acting in cooperation, and payment therefor shall be made on proper vouchers by the special fiscal agent of the Reclamation Service and the State Department of Engineering in the proportion of two-thirds and one-third, respectively, to be adjusted monthly as nearly as practicable.

7. On completion of the surveys and investigations herein provided for, all field notes, original plans, calculations, reports, and other data acquired or prepared during the investigations and surveys shall be filed with the United States Reclamation Service, and copies thereof furnished to the State Engineer of the State of California, and to the Iron Canyon Project Association for official record; the said original records shall be accessible at all times to the State Engineer or his duly authorized representative and to the duly authorized representative of the Iron Canyon Project Association upon application.

8. The report of the said surveys and investigations shall be promptly made by the officer of the Reclamation Service in charge, outlining the scope of the investigations, giving detailed estimates of the Iron Canyon project, with suitable explanatory maps, plans, and other documents as exhibits, together with a summary of expenses incurred in the investigations. Such report shall also contain specific conclusions and recommendations as to the future policy considered the most advisable to be followed by the United States and the State of California in utilizing, reserving, or disposing of public lands, waters, reservoirs and power sites, and other natural resources, conforming with the plan of development indicated by these investigations as being to the highest

public advantage. The conclusions and recommendations shall be jointly agreed upon on the one part by the officer of the Reclamation Service having charge of the work subject to the approval of the Director of the Reclamation Service, and on the other part by the State Engineer. In case of their failure to agree, the Reclamation Service and the State Engineer shall submit separate conclusions and recommendations, both of which shall be embodied in the report and published. In all reports the names of the parties hereto shall be shown and also the names of the cooperating officers.

9. The expenditures shall be borne equally by the parties hereto, and the report shall show such expenditures which shall include the usual overhead charges of the Reclamation Service. In case the entire amount contributed is not spent there shall be returned to each party the excess of the money contributed by it over its one-third share of the expenditures.

10. Where the operations of this contract extend beyond the current fiscal year it is understood that the contract is made contingent upon Congress making the necessary appropriation for expenditure thereunder after such current year has expired. In case sufficient appropriation necessary to carry out this contract is not made, the parties hereto hereby release the United States from all liability due to the failure of Congress to make such appropriation.

11. No Member of or Delegate to Congress, or Resident Commissioner, after his election or appointment, or either before or after he has qualified and during his continuance in office, and no officer, agent, or employee of the Government shall be admitted to any share or part of this contract or agreement, or to any benefit to arise thereupon. Nothing, however, herein contained shall be construed to extend to any incorporated company, where such contract or agreement is made for the general benefit of such incorporation or company, as provided in section 116 of the act of Congress approved March 4, 1909 (35 Stat. L., 1109).

In witness whereof this contract has been executed by the parties hereto this day and year first above written.

UNITED STATES OF AMERICA,
By FRANKLIN K. LANE,
Secretary of the Interior.
STATE OF CALIFORNIA,
By W. F. MCCLURE,
State Engineer, State Department of Engineering.
IRON CANYON PROJECT ASSOCIATION,
By JOHN F. ELLISON, *President.*
By A. L. CONARD, *Secretary.*

SCOPE OF INVESTIGATIONS.

The various features of the investigations undertaken have been—

A. Explorations for a dam site by means of test borings, drifts, and geological studies.

B. Location of the main canal.

C. Studies of the water supply, duty of water, irrigable area, and other matters bearing on the feasibility and economic limits of the project.

D. An estimate of the cost of the project.

The canal location was done by the State Department of Engineering under the supervision of the State Engineer. The State cooperated also in the geological studies at Iron Canyon, and State funds

were used for part of the drill work. The explorations at Iron Canyon and the various studies and cost estimates were made by the United States Reclamation Service.

A topographical survey of the irrigable lands has not been made, as the funds available were not sufficient, and such survey is not considered essential in determining the feasibility of the project. The topographic sheets of the Geological Survey cover the irrigable area and furnish much valuable information.

Since 1914 some conditions affecting the project have changed so as to alter materially the conclusions to be drawn from the former investigations and making reconsideration desirable. In the interval appropriations of water from the Sacramento River have increased to such an extent that the low-water flow is practically all taken, leaving an insufficient water supply available for this project without storage. Prices of materials, labor, and equipment have advanced so much as to make large additions to the former estimates of cost. The formation of the Anderson-Cottonwood irrigation district, lying partly within the proposed Iron Canyon reservoir, has added to the estimated cost of some of the land to be acquired for reservoir. On the other hand, such increases are partly offset by recent advances in land values and prices of farm products, increasing the value of water for irrigation.

FEASIBILITY.

The feasibility of the project depends upon the following points:

A. Lands to be benefited by irrigation must be found in sufficient areas so located as to be practically irrigable under the proposed plan.

B. A water supply must be available, adequate to the requirements of the project.

C. The reservoir must have sufficient capacity to provide the required storage, and it must be free from excessive leakage.

D. Since storage is required a site must be found where a storage dam can be built that will be safe and within a reasonable limit of cost.

The above are physical necessities toward the feasibility of the project. The absence of any one of these requisites would defeat the project permanently. Each of these points will be discussed in order.

In addition to these primary essentials, feasibility depends also upon certain other conditions, the failure of any one of which would defeat the project, at least temporarily, as follows:

E. The cost of the project per acre irrigated must not be more than the benefits to be derived from it.

F. Formation of the irrigation district or districts must be accomplished, embracing the lands to be benefited.

G. Funds for construction must be provided.

Feasibility does not depend upon the cooperation of other interests in the matter of flood control or benefit to navigation. If any increase of cost of construction or operation is occasioned by the inclusion of features for such purposes the increase of cost at least should be borne by the interests benefited. While the net result might be favorable to the irrigation project, its feasibility should be determined independently of such considerations.

Power development should be included in the plans, the installation to be made when it becomes economically profitable. The influence of the power feature on feasibility of the project is considerable, due to its effect in reducing the cost for irrigation.

The character of the project and its economic limits were developed in a general way in the investigations of 1914, referred to above. Many plans were considered and discussed in the report with the purpose of finding the most feasible plan and the economic limits of the project. The limit of the project is governed mainly by the reservoir capacity, and that in turn by the height to which it is practicable to build the dam. The limits of 225,000 acres, with available reservoir capacity of 603,000 acre-feet, tentatively fixed in the former report, are approximately consistent and apparently about the economic limits. The irrigable area can not be increased without considerable extension of the main canal to detached areas, and it appears impracticable to raise materially the height of the dam.

IRRIGABLE LANDS.

The irrigable area lies in Tehama and Glenn counties on the west side of the river, with a small area on the east side opposite to Red Bluff. The main canal location forms the western boundary, and in general the eastern boundary is formed by the river in Tehama County and by the Central Canal in Glenn County. The Orland project is deducted, as well as certain other areas, either having a present water supply or for other reasons not likely to join the irrigation district. As the district is not yet formed there is some uncertainty regarding some of these excluded tracts.

The calculation of areas is as follows:

		Acres.
In Tehama County, gross area west of river		117,120
Deductions:		
Capay Rancho	6,140	
Towns	1,920	
Four high areas near Corning	3,840	
Other areas not likely to come in	7,070	
Total deductions		18,970
		98,150

		Acres.
Deduct 10 per cent for roads and other nonirrigable areas		9,815
Net area Tehama County, west side		88,335
Net area Tehama County, east side		6,400
Total Tehama County		94,735
In Glenn County, gross area		159,360
Deductions:		
Orland project	25,440	
Capay Rancho	5,120	
Kaiser tract	1,880	
Loam Ridge	800	
Total deductions		33,240
		126,120
Deduct 10 per cent for roads, etc		12,612
Net area Glenn County		113,508
Net area Tehama County		94,735
Total net area of project		208,243

The irrigable lands of the proposed Stony Gorge extension of the Orland project lie within the above area, and if that extension should be built taking water from Stony Creek the area for the Iron Canyon project would be reduced by about 25,000 acres.

Lands now irrigated within this proposed project by pumping from the river and from wells and from the unregulated flow of small streams amount to about 13,000 acres in Tehama County and about 8,700 acres in Glenn County outside of the Orland project. It is assumed in making the above deductions that a considerable part of these lands now irrigated will come into the project on account of their present water supply being insufficient or too expensive.

The calculations on water supply for the project, sufficiency of storage, main-canal capacity, etc., are based on an irrigable area of 225,000 acres. Although the estimate of area given above is less than that amount it is probable that other and additional lands may be supplied, either by pumping to land above the canal or by extending the canals to areas beyond the described limits. This assumption is on the safe side as to water supply, but as to cost per acre may be a little misleading if the total area supplied should fall below 225,000 acres.

DUTY OF WATER.

The subjects of irrigable area and duty of water are discussed in the former report at page 76. In climate and soil this project is similar to the Orland project. As a result of further experience on that project it is now assumed that it will be necessary to divert

4.125 acre-feet per acre per annum at the head of the main canal instead of 3 feet. This will allow of a loss of one-third in the distributing system, leaving 2.75 feet on the land.

The main canal is designed to be concrete lined throughout, and in the course of time the laterals would also be lined, resulting in more economical use of water. The growing of rice, now rapidly increasing in this valley, requires much more water per acre than the amount here assumed, about two and one-half times as much. If this industry should continue to increase, the estimate of acreage which can be supplied by this project must be revised.

The quantity to be diverted from the reservoir at 4.125 acre-feet per acre for 225,000 acres would be 928,125 acre-feet per annum, distributed throughout the irrigating season as follows:

	Feet per acre.	Acre-feet.	Per cent.	Second-feet.
March	0.2475	55,687	6	905
April	.4125	92,812	10	1,560
May	.5775	129,938	14	2,115
June	.7838	176,344	19	2,965
July	.8663	194,906	21	3,170
August	.7837	176,344	19	2,965
September	.2887	64,969	7	1,091
October	.0825	18,563	2	302
November	.0825	18,562	2	312
Total	4.1250	928,125	100	.....

WATER SUPPLY.

The following table gives the mean flow of the Sacramento River at Red Bluff, being the average for the years 1902 to 1919, inclusive.

	Second-feet.	Acre-feet.		Second-feet.	Acre-feet.
January	23,845	1,466,000	August	5,030	309,300
February	31,820	1,780,000	September	4,950	294,200
March	29,010	1,784,000	October	5,600	344,200
April	20,970	1,246,000	November	8,400	499,600
May	14,380	885,000	December	10,830	666,000
June	9,090	540,500			
July	6,040	371,200	The year	.....	10,186,000

The present use of water from the Sacramento above Knights Landing, together with applications on file with the State Water Commission for further diversions, amounted to about 5,793 second-feet up to May 12, 1919, which is nearly equal to the average flow of the river in July, and exceeds the average flow of August and September at Red Bluff. Additional applications are continually being made and the low water flow is being increasingly drawn upon. From this it is evident that there is very little water supply available for the Iron Canyon project without storage.

It is also obvious that, given sufficient reservoir capacity, the water supply available for storage is ample for the proposed area of land. Assuming that all flow above 10,000 second-feet is available for storage, the average year would furnish a supply as follows:

	Second-feet.	Acre-feet.		Second-feet.	Acre-feet.
January	13,845	852,000	August	0	0
February	21,820	1,222,000	September	0	0
March	19,010	1,170,000	October	0	0
April	10,970	653,000	November	0	0
May	4,380	269,400	December	830	51,000
June	0	0			
July	0	0	The year		4,217,400

In the period from 1896 to 1919, inclusive, embracing the whole record of river discharge, the amount available for storage above a flow of 6,000 second-feet during May to August, inclusive, 5,000 second-feet in April and September, and above 4,000 second-feet during October to March, inclusive, would have exceeded the irrigation requirements (928,125 acre-feet) in every year. But while the amount available for storage is sufficient there would be a deficiency in some years owing to the limited storage capacity.

RESERVOIR CAPACITY.

The capacity of the reservoir at 10-foot intervals is given in the former report on page 58, referring to the upper dam site. For the lower site the areas and storage capacities are approximately as follows:

Elevation.	Flooded area.	Storage.	Elevation.	Flooded area.	Storage.
	Acres.	*Acre-feet.*		*Acres.*	*Acre-feet.*
253	0	0	340	4,750	134,600
260	229	800	350	6,555	191,200
270	341	3,700	360	9,640	272,100
280	556	8,100	370	12,863	384,700
290	916	15,500	380	16,590	531,900
300	1,278	26,500	390	21,146	720,600
310	1,751	41,600	392.5	22,465	775,100
320	2,437	62,600	400	27,178	961,300
330	3,615	92,800			

Under the plans the dam is to be both a storage and a diversion dam, the main canal being taken directly from the reservoir. The assumed elevation of spillway crest is 392.5 with high-water elevation at 400. The outlet at the head of the main canal is at elevation 350 for canal-water surface, with elevation 340 for bottom of opening. Thus there is, with a full reservoir, 42.5 feet of water above canal-water surface and 52.5 feet above bottom of outlet. With a reservoir stage between 340 and 350 only a part of the full canal capacity could be drawn out.

The available reservoir capacity above elevation 350 up to the spillway crest is 584,000 acre-feet, and above 340 to spillway crest is 640,000 acre-feet, for the lower site. As the available reservoir capacity is only about two-thirds of the annual irrigation requirements there must be additions to the storage or use of part of the natural flow during at least a part of the irrigating season.

In making calculations on the sufficiency of reservoir capacity certain assumptions are necessary. These relate to losses from the reservoir by evaporation and seepage, quantity of water to be passed by the dam for interests below, and the irrigation requirements of this project. The irrigation requirements are presented on page 11. Losses from the reservoir are based on the results of experiments by the Department of Agriculture at Chico, Calif., in 1904 and 1905, in regard to monthly evaporation from water surfaces. The losses are assumed as follows, consideration being given to the probable stage of the reservoir each month.

	Acre-feet.		Acre-feet.
January	150	August	8,300
February	500	September	3,900
March	3,100	October	1,800
April	7,300	November	1,000
May	11,700	December	500
June	13,550	The year	64,000
July	12,200		

On May 17, 1919, application was made to the State Water Commission for water and storage rights on the Sacramento River for the Iron Canyon project. An attempt has been made to ascertain the total amount of the prior and adverse water rights on this stream, the supply for which must be permitted to pass Iron Canyon. For various reasons it has been found to be impossible to fix exactly the amount of such rights, but from the best information available the aggregate is between 5,500 and 6,000 second-feet. While the use of water from the natural flow of the Sacramento may increase in the future it can never exceed about 6,000 second-feet throughout the season on account of the natural limitation of the low flow of the river. Considering 6,000 second-feet as a maximum to be used by prior claimants in July, according to the proportions given on page 11, the use in the several months of the irrigation season would be:

	Second feet.		Second feet.
March	1,715	August	5,430
April	2,860	September	2,000
May	4,000	October	570
June	5,430	November	570
July	6,000		

It is therefore assumed that it would be sufficient to satisfy prior rights of 6,000 second-feet were permitted to pass the dam during May to August, inclusive, 5,000 second-feet in April and September, and

4,000 second-feet during the remainder of the year, with the understanding that if at any time the natural flow into the reservoir should fall below the corresponding amount here mentioned then only the natural inflow need be passed; in other words, storage is not provided for the prior rights. The excess inflow above the amount thus required to pass the dam would be available for storage for the Iron Canyon project. If the accretions to the river or return waters may be depended upon to augment materially the flow available for the water users below Iron Canyon, then these assumed limits may be accordingly lowered.

SUMMARY OF ASSUMED CONDITIONS.

A. Storage dam located at the lower site, one-half mile below the gaging station in Iron Canyon.

B. Elevation of spillway, 392.5.

C. Elevation of bottom of canal intake, 340.

D. Available reservoir capacity, 640,000 acre-feet.

E. Irrigation requirement per annum, 928,125 acre-feet.

F. Reservoir losses per annum, 64,000 acre-feet.

G. Storage permitted of the natural flow in excess of 6,000 second-feet during May, June, July, and August, in excess of 5,000 second-feet in April and September, and in excess of 4,000 second-feet during the remainder of the year.

H. Net irrigable area, 225,000 acres.

Under the above conditions it is found that if the amount of water available for storage and use is sufficient to fill the reservoir and supply the amount diverted up to June 8, so that the reservoir would be full on that date, there would be sufficient water for the remainder of the season without further storage.

An examination of the discharge record of the river for the past 25 years, 1896 to 1920, inclusive, discloses that with the reservoir in operation there would have been a deficiency of water required to be diverted from the reservoir in seven of those years as follows:

	Per cent.
1898	7.9
1899	3.4
1900	1.1
1901	.6
1918	13.0
1919	1.1
1920 (up to Oct. 1)	16.4

The other 18 years would have had a full water supply. Such deficiencies, occurring on an average in one year out of three or four, are not a serious detriment to the project, but they indicate that under the assumed conditions the limit of area that can be practicably supplied from the reservoir is about reached. As there is no hold-over capacity the years of low flow limit the project.

With a reservoir having an available capacity of 713,000 acre-feet all of these deficient years could have been fully supplied except 1920, in which year there would have been a shortage of 2 or 3 per cent if all available water could have been stored.

SILT.

No data are available regarding the amount of silt carried by the river. The percentage is not large, but owing to the large volume of flow the aggregate quantity of silt must be considerable. Cottonwood Creek, coming into the reservoir from the west, probably carries a large percentage of silt when in flood.

The deposition of silt within the reservoir would depend to a large extent on the manner of operation during the winter or high-water season. If the stage is to be maintained not lower than elevation 340, that of the canal intake, at all times in the interests of power production and to keep driftwood away from the dam, then the greater part of the silt brought by the river would be deposited in the reservoir. But if all the storage should be released in times of flood there would be no deposition of silt at such times, and a considerable quantity of silt previously deposited would be cut out and carried on down the river. Thus the prevention of silt deposit would interfere with the continuous power production.

The percentage of reservoir capacity below the canal intake is 17.8 per cent, leaving 82.2 per cent available for diversion. There is no excess of capacity to allow for the deposit of silt except in the 134,600 acre-feet below the canal intake. Any considerable deposits above that level would seriously reduce the water supply for irrigation in the years of shortage.

To increase the height of the dam does not seem practicable on account of the heavy destruction of property that would be necessary for a larger reservoir, and the topography at and near the dam site is not favorable for any increase in height above that of the present plans. The ultimate solution of the silt problem would probably be the construction of other or auxiliary reservoirs farther upstream or on its tributaries.

IRON CANYON DAM SITE.

The investigations and drill borings of 1913–14 for a dam site in Iron Canyon indicated foundation conditions that were not altogether satisfactory and the need of more extended explorations became obvious. Under the present contract additional test borings were begun in June, 1919, and finished in May, 1920.

Three sites in Iron Canyon have been considered and investigated with regard to a location for the dam. In this report these sites are referred to as the upper, middle, and lower sites. The investigations indicate that there are no other sites in the canyon worthy of consid-

eration. The upper site is at the upper end of the canyon above Paynes Creek. This is the one considered most favorably in the 1914 report, and here the "B" series of holes was drilled in 1914. The "D" series of holes of the present work relates to the same, or upper site, and these were extended to investigate the formations under the proposed spillway.

The middle site is about a mile and a half below the upper site. At or near this site holes C–1 and C–2 were drilled in 1914. Holes F–1 and F–2, drilled in 1919, also relate to this site.

The lower site is a mile and a half below the middle site, and is located one-half mile below the gaging station at the lower end of the canyon. At this site the 16 holes of the "E" series were drilled.

Two drifts were excavated at the upper site to expose the bed plane under the lava. One drift is in the north wall of the river canyon just below the dam site. The other is in the west wall of Paynes Creek Canyon. At the lower site a drift was dug in the agglomerate rock on the east side of the river opposite to E–3 to a length of about 35 feet.

RECORD OF DRILL BORINGS, 1919–20.

The logs of the "A," "B," "C," "D," and "F" series of holes, also of E–1 to E–4, inclusive, are given in Appendix No. 1, pages 51 to 57. Following are the logs of holes E–5 to E–16, inclusive.

LOG OF HOLE E–5.

Elevations.	Thickness.	Description of formations.
281.0–259.0	22.0	Earth.
259.0–200.0	59.0	Agglomerate, soft, no core except of lava blocks.
200.0–198.0	2.0	Black sand, caving
198.0–187.0	11.0	Blocks of lava, broken lava, and loose material. Caving. Water returns. Cemented 4 times.
187.0–112.0	75.0	Agglomerate, soft, no core except of lava blocks.
112.0– 98.0	14.0	Agglomerate, same as 187 to 112. Slightly harder near the bottom where a few small pieces of matrix core were obtained.
98.0– 88.0	10.0	Tuff, sandy. A few pieces of core recovered.
88.0– 87.0	1.0	Soft seam, rods twisted down by hand. Small flow of artesian water from here.
87.0– 85.5	1.5	Tuff, claylike. Some core recovered.

LOG OF HOLE E–6.

253.5–247.7	5.8	Water of river.
247.7–247.0	.7	Sand and gravel.
247.0–232.0	15.0	Agglomerate. Cores of lava plums and a few small pieces of agglomerate matrix recovered. The rig had been placed on barge and moved to middle of river to drill this hole. The barge could not be held steadily in position and it was unsafe to continue. The force of the wind, waves, and current gradually dragged the anchors, tending to bend the drill rods and casing.

LOG OF HOLE E–7.

275.5–267.5	18.0	Earth and some loose boulders.
257.5–253.5	4.0	Gravel and sand.
253.5–240.5	13.0	Agglomerate, soft, no core except lava blocks.
240.5–238.5	2.0	Sand, caving.
238.5–180.5	58.0	Agglomerate, soft, no core except lava blocks.
180.5–129.0	51.5	Do.
129.0–125.5	3.5	Tuff, smooth claylike.
125.5–121.0	4.5	Tuff containing small pebbles. Small flow of artesian water at 125.5. No caving below 238.5.

LOG OF HOLE E-8.

Elevations.	Thickness.	Description of formations.
330.1–322.1	8.0	Earth and boulders.
322.1–302.6	19.5	Cemented gravel and cobbles.
302.6–280.8	21.8	Brown, sandy tuff. Gravel seen at 288.1.
280.8–270.1	10.7	Agglomerate. Cores of lava plums only. Drove casing to 302.6. Used dynamite to get through cemented gravel and cobbles.

LOG OF HOLE E-9.

343.8–333.8	10.0	Earth, gravel, and boulders.
333.8–323.8	10.0	Tuff, reddish brown, sandy, fine.
323.8–314.8	9.0	Cemented gravel and small boulders.
314.8–295.8	19.0	Cemented gravel and large boulders.
295.8–290.8	5.0	Alternating strata of coarse and fine sand, like sandy tuff: caving.
290.8–288.3	2.5	Brown, sandy tuff. Lava boulder at 288.3.
288.3–284.8	3.5	Reddish-brown tuff. Some core recovered.
284.8–271.8	13.0	Agglomerate. Cores of lava plums only. Hole stood open and water was coming back at the finish with casing down to 288.3.

LOG OF HOLE E-10.

416.1–406.1	10.0	Loose earth and boulders.
406.1–399.1	7.0	Tuff, clay-like.
399.1–380.1	19.0	Tuff, dark, sandy.
380.1–373.1	7.0	Tuff, dark, sandy.
373.1–369.1	4.0	Sand seam: not very coarse. Some water lost here.
369.1–360.1	9.0	Tuff, dark, sandy.
360.1–340.1	20.0	Tuff, yellow, fine grained.
340.1–334.5	5.6	Agglomerate, a few pieces of core from lava plums recovered. Hole in good condition at finish. (Mr. Hamlin thought this was not agglomerate, but probably conglomerate, and that the agglomerate was lower down. H. J. G.)

LOG OF HOLE E-11.

397.7–395.7	2.0	Black soil.
395.7–379.7	16.0	Tuff varying from yellow clay-like to dark coarse sandy and light coarse sandy. Cores of each kind recovered.
379.7–375.7	4.0	Yellow, clay-like tuff.
375.7–372.7	3.0	Coarse, sandy tuff.
372.7–355.7	17.0	Yellow, clay-like tuff.
355.7–341.7	14.0	Sandy tuff or hard-packed sand.
341.7–341.2	5.0	Seam of rather coarse sand.
341.2–327.7	13.5	Hard-packed sand or sandy tuff.
327.7–320.7	7.0	Finer-grained, sandy tuff.
320.7–314.7	6.0	Black sand seam, not very coarse.
314.7–308.7	6.0	Agglomerate. Some of the core of different kinds of tuff was recovered and in the agglomerate cores of lava plums were secured.

LOG OF HOLE E-12.

379.0–377.0	2.0	Black soil.
377.0–370.0	7.0	Yellow, clay-like tuff.
370.0–361.0	9.0	Coarse, brown, sandy tuff.
361.0–359.0	2.0	Finer-grained, brown tuff.
359.0–358.0	1.0	Yellow, clay-like tuff.
358.0–357.0	1.0	Black sand seam.
357.0–352.0	5.0	Brown, sandy tuff, fine grained.
352.0–348.0	4.0	Brown, sandy tuff, coarse grained.
348.0–346.0	2.0	Black sand seam.
346.0–340.0	6.0	Brown, sandy tuff, coarse.
340.0–338.0	2.0	Yellow clay-like tuff.
338.0–334.0	4.0	Brown tuff, fine grain.
334.0–287.0	47.0	Hard-packed, brown, sandy tuff.
287.0–283.0	4.0	Agglomerate. Cores of lava plums of agglomerate recovered, also of different kinds of tuff. Loss of water in this hole gradually increased until at about elevation 339 it became necessary to put in casing, which stopped the leakage. As the hole was finished there was some leakage, but not much.

LOG OF HOLE E-13.

Elevations.	Thickness.	Description of formations.
379.9–378.9	1.0	Yellow soil.
378.9–374.9	4.0	Sandy, yellow tuff.
374.9–353.9	21.0	Cemented gravel and boulders.
353.9–345.9	8.0	Yellow, fine-grained tuff.
345.9–336.9	9.0	Dark, sandy tuff.
336.9–328.9	8.0	Black or brown, coarse, sandy tuff.
328.9–305.9	23.0	Dark, hard-packed, sandy tuff.
305.9–300.9	5.0	Yellow, clay-like tuff.
300.9–296.9	4.0	Brown, fine-grained tuff.
296.9–293.9	3.0	Agglomerate. Cores of tuff recovered, also of lava plums. Loss of water began at elevation 336.9 and continued to the end, but was not considerable. A quantity of muck was noticeable in the hole each time rods were lowered. To elevation 353.9 this hole was very difficult and progress slow.

LOG OF HOLE E-14.

371.3–366.3	5.0	Loose red soil and boulders.
366.3–365.3	1.0	Tuff, reddish brown.
365.3–352.8	12.5	Cemented gravel and boulders.
352.8–347.8	5.0	Tuff, dark sandy fine grained.
347.8–346.8	1.0	Tuff, yellow, clay-like.
346.8–344.3	2.5	Tuff, dark sandy fine grained.
344.3–340.3	4.0	Tuff, coarse brown sandy. Rods twisted down by hand through this. Beginning to lose water.
340.3–333.3	7.0	Tuff, brown fine grain. Rods held.
333.3–326.3	7.0	Brown hard-packed sand.
326.3–305.3	21.0	Tuff, coarser brown sandy. Rods twisted down by hand through material from 333.3 to 305.3. Losing some water still, but not much.
305.3–304.3	1.0	Tuff, finer grained, brown.
304.3–296.3	8.0	Tuff, coarse, brown, sandy. Rods twisted down through this.
296.3–294.3	2.0	Seams of fine, yellow tuff.
294.3–289.8	4.5	Tuff, coarse, brown, sandy.
289.8–286.3	3.5	Agglomerate. Some tuff core recovered, also core of lava plums. Hole was caving considerably at finish. Casing was put down to elevation 351.3 by using dynamite.

LOG OF HOLE E-15.

368.4–366.9	1.5	Red soil and boulders.
366.9–365.4	1.5	Red tuff.
365.4–353.4	12.0	Cemented gravel and boulders.
353.4–351.4	2.0	Brown sand seam. Lost all water. Drove casing to 350.4 to stop leakage.
351.4–338.4	13.0	Tuff, fine grained, brown.
338.4–334.4	4.0	Tuff, brown, coarse, sandy. Losing some water.
334.4–329.4	5.0	Tuff, brown, fine.
329.4–325.4	4.0	Tuff, yellow, fine.
325.4–308.4	17.0	Tuff, brown, sandy fine. Rods twisted slowly down by hand in this material.
308.4–298.4	10.0	Same as 325.4 to 308.4, but a little coarser.
298.4–293.4	5.0	Same as 325.4 to 308.4.
293.4–289.4	4.0	Tuff, brown, sandy, coarse.
289.4–284.4	5.0	Tuff, brown, sandy, finer, with some seams of yellow fine-grain tuff.
284.4–282.4	2.0	Tuff, brown, coarse, sandy.
282.4–278.4	4.0	Agglomerate. Some core of tuff and of lava plums recovered. Hole lost some water all along but not much. Hole caved considerably all along.

LOG OF HOLE E-16.

270.8–266.8	4.0	Earth and boulders.
266.8–245.8	21.0	Agglomerate, soft, caving; had to use cement.
245.8–216.8	29.0	Agglomerate, not so soft. Not caving.
216.8–197.3	19.5	Agglomerate; ground is firm; getting a few pieces of agglomerate core.
197.3–184.8	12.5	Broken agglomerate, caving; cemented twice.
184.8–132.3	52.5	Agglomerate, not caving.
132.3–122.8	9.5	Tuff. Small flow of artesian sulphur water at 128.8. Cores of agglomerate and tuff recovered. Hole in good condition at finish.

At the lower dam site, in the drift mentioned above, a test was made to ascertain the bearing capacity of the soft agglomerate rock. No measurable settlement or compression occurred under a pressure of 39.5 tons on one square foot.

GEOLOGY.

The explorations have been extended by geological studies throughout the canyon and surrounding country with the aid of the results of the test borings. Two geologists working independently were employed, one by the State of California, the other by the United States Reclamation Service.

On August 12 and 13, 1919, Prof. Andrew C. Lawson, of Berkeley, made examination of the upper and middle sites for the State. His report is included as Appendix No. 3 of this report. At the time of Professor Lawson's field work at Iron Canyon, the lower site had not been suggested, and no attention was given to it then. His recommendations for additional borings at the middle site were later carried out by drilling holes F–1 and F–2, the results of which caused this site to be abandoned.

Extensive field studies of Iron Canyon and vicinity were made by the late Homer Hamlin of Los Angeles, consulting engineer and geologist for the United States Reclamation Service, on August 15 to 23, inclusive, and on December 14 and 15, 1919. His report is included as Appendix No. 1 of this report.

After completion of the drill borings a board of consulting engineers was convened at Red Bluff, Calif., on May 5, 6, and 7, 1920, to consider the dam sites and type of dam. The board selected the lower site in Iron Canyon, or Location III. The report of the consulting engineers is printed as Appendix No. 2 of this report.

NAVIGATION.

No benefits to navigation are contemplated in these plans except such as may result incidentally from flood regulation. From the foregoing discussion it is obvious that if the works were to be used to maintain any minimum above the natural flow in summer there would be such a shortage of irrigation water as would seriously impair if not entirely defeat the project.

FLOOD CONTROL.

It has been proposed heretofore to regulate floods by means of this reservoir down to a maximum limit of 100,000 second-feet. Since the year 1895 floods in the Sacramento at Red Bluff have exceeded 100,000 second-feet in 21 months; exceeded 150,000 second-feet in 7 months; and exceeded 200,000 second-feet in 2 months, with a maximum recorded flow of 278,000 second-feet. The usual flood season is in January, February, and March, with an occasional flood in November, December, and April.

This subject is ably discussed at page 43 of the 1914 report. The manner of operating the reservoir so as to effect the greatest possible control of floods and at the same time store water sufficient for

irrigation is a matter requiring considerable study and it is probable that the best procedure can be developed only by actual experience in operating the completed works. However, an approximate idea of the possible results may be attained by consideration of the data at hand.

The gates of the dam as shown in Exhibit M would pass 159,000 second-feet without necessitating a rise of water level of the reservoir above elevation 340. If the outflow were restricted to 100,000 second-feet the reservoir would fill from elevation 340 to elevation 392.5 with various rates of inflow in the times shown in the following table:

Inflow, second-feet.	Time to fill.	Inflow, second-feet.	Time to fill.
150,000	6.40 days.	300,000	38.40 hours.
200,000	3.20 days.	350,000	30.70 hours.
250,000	2.13 days.	400,000	25.60 hours.

Assuming the reservoir filled to elevation 392.5 with available storage of 640,000 acre-feet, this storage could be released by an outflow of 100,000 second-feet with various rates of inflow in the following times: 10,000 second-feet inflow, reservoir would empty in 3.55 days; 20,000 second-feet inflow, 4 days; 40,000 second-feet, 5.33 days; 60,000 second-feet, 8 days; 80,000 second-feet, 16 days.

With the reservoir empty (at elevation 340) at the beginning of the flood, any flood of record could have been passed without exceeding an outflow of 100,000 second-feet. But if the reservoir had been held empty for flood detention throughout January, February, and March, it would have been impossible in some years to fill the reservoir after April 1. In 1898 it would have been necessary, under the conditions assumed on page 14, to store the whole amount available after some day in January, and in 1920 some day in the previous December.

During the months of January, February, and March, for the maximum effect toward flood regulation, the reservoir should be held at the lowest stage consistent with the requirement of filling the reservoir by April 1, such stage at any time to be determined by the prospects of flood as indicated by weather conditions interpreted by experience. Whether the occurrence of a flood exceeding 100,000 second-feet could be anticipated long enough in advance to empty the reservoir before the inflow reached 100,000 second-feet would depend upon several indeterminate factors, but in practice, as the prospects for a flood increased, the stage of the reservoir would be lowered, and if it could not be entirely emptied, at least a considerable flood-detention capacity could be provided.

Floods greater than any of record, both in amount and duration, are likely to occur and it may happen that the limit in some rare in-

stances can be reduced only to some amount greater than 100,000 second-feet, while in most cases the maximum outflow could be brought below that amount. The greatest possible effect of the reservoir in any case would be the retention of 640,000 acre-feet from the peak of the flood. A comparatively small amount of additional storage could be obtained by lowering the stage below elevation 340, but as that would cut down the minimum power head it is not considered. The proper time to begin storage in any case so as to take 640,000 acre-feet from the peak of the flood and reduce it to the lowest attainable uniform flow would be a matter of judgment at the time, difficult to estimate, and probably would seldom be exactly accomplished. However, an approximation which could be secured after some experience would have nearly the same value in effect.

The value of the reservoir for reducing floods lies mainly in the possibility of so operating the gates of the dam as to produce the desired effect rather than in any changes in or additions to the design for this purpose. Without such intentional regulation the reservoir would have a comparatively small beneficial effect upon floods, while with proper regulation of the gates the flood peaks could generally be greatly reduced.

POWER DEVELOPMENT.

The plan provides for the constant discharge from the reservoir into the river below the dam of 3,700 to 6,000 second-feet at heads varying from 87 to 130 feet, which permits the development of a minimum of 29,000 and a maximum of 70,000 horsepower at 80 per cent efficiency. Taking the mean at 50,000 horsepower, valued at $150 per horsepower, gives $7,500,000 as the value of the power plant, which amount may be considered an incidental credit to the irrigation project.

DRAINAGE.

The Orland project has been in operation about 10 years and drainage has not yet become necessary there. The experience on that project warrants the belief that drainage may never be a serious problem on the Iron Canyon project.

MAIN CANAL.

The location of the main canal was begun in June, 1919, under the supervision of the State Engineer. Commencing at the heading on the reservoir, the line was carried down the west side of the valley, to the west of Red Bluff, Corning, Orland, and Willows, to the south line of Glenn County, a distance of 69.5 miles. The assumed

hydraulic elements of the main canal for the west side are shown in the following table, based upon the requirements for water previously mentioned under the title of "Irrigable lands."

Assumed dimensions and hydraulic elements, West Side main canal.

Point.	Distance.	Depth.	Bottom width.	Slope.	Capacity.
	Miles.	*Feet.*	*Feet.*		*Sec. ft.*
Head	0.00				
To Dibble Creek	4.25	12	32	0.0002	3,060
To Redbank Creek	10.23	13	22	.0002	3,060
To Coyote Creek	13.25	13	20	.0002	2,907
To Elder Creek	16.66	13	24	.0002	2,810
To McClure Creek	19.30	11	24	.00025	2,660
To Thomas Creek	21.87	11	22	.00025	2,500
To West of Corning	25.33	11	21	.00025	2,420
To Rice Creek	28.91	10.5	21	.00025	2,215
To Glenn County line	35.35	10	20	.00025	1,945
To Station 2286	43.05	9.5	16	.0003	1,655
To Station 2776	52.34	7	16	.0004	1,060
To Station 3060	57.70	5.8	10	.00055	620
To Station 3470	65.50	3.2	7	.001	206
To Colusa County line	69.50	2	4	.002	78

These dimensions have been assumed for the purpose of estimating cost and should not be taken as a final design. The inside slopes are 1 to 1 from the head to Dibble Creek, and 1½ to 1 for the rest of the canal, which is to be lined with concrete 4 inches thick throughout. The coefficient of roughness used is $n=0.014$. Top width of banks is 14 feet from the head to McClure Creek, 12 feet from that point to station 2286, 10 feet to station 3060, 8 feet to station 3470, and 6 feet from that point to the Colusa County line. Freeboard is 3 feet from the head to station 3060, 2.8 feet to 3470, and 2 feet from that point to the end. Velocities range from 5.47 to 5.97 feet per second in the canal, with about 8 feet in the concrete aqueducts and siphons. Drops are introduced at four places as follows:

Stations 2130 to 2180, 20.95 feet (incline). Station 2550, 2.34 feet (vertical). Station 3060, 10.68 feet (vertical). Station 3220, 8 feet (vertical).

The capacity of the East Side canal is assumed at about 110 second-feet, and in the estimates of cost it is included in the lateral system.

ESTIMATE OF COST.

STORAGE DAM.

Site 2,600 feet below United States Geological Survey gaging station.

Descriptive notes.

General plan:

Area of project	acres	225,000
Total net storage provided	acre-feet	640,000
Capacity of siphon spillway	second-feet	200,000

Capacity of overflow spillway with water supply at elevation 405.5	second-feet	79,000
Capacity of flood-control gates with water supply at elevation 340	second-feet	159,000
Total capacity of spillways and flood-control gates with water supply at elevation 405.5	second-feet	547,000
Total power development	horsepower	60,000

DAM.

Estimates have been made of three alternative structures—Type I, Type II, and Type III. Type I consists of a gravity section throughout. Type II consists of buttressed sections in place of gravity section, except for flood-control and power-house portions, which are the same as in Type I. Type III consists of an earth embankment with concrete core wall in the place of the gravity or buttressed portions of the other two types, except the flood-control and power-house portions, which are of gravity section, as in Types I and II.

The various sections used for Types I and II are shown on Exhibits K, L, M, and N, following page 76. The embankment section used for Type III is as follows:

Elevation of crown	feet	410.5
Width of crown	do	20
Upstream slope		6:1
Downstream slope		2:1
Concrete core wall, top elevation	feet	408.5
Concrete core wall, thickness at top	inches	12
Core wall, side batter for heights up to 60 feet		1:30

For heights of core wall over 60 feet, the sides are vertical below an elevation 60 feet from top of wall. Core wall is founded on and is a continuation of the deep cut-off wall common to all types of dam.

The counterfort abutments on each side of the river are designed for foundation on Agglomerate No. 1. No riprap or other slope protection is provided since the 6:1 slope is assumed to be the natural beaching slope of the embankment material.

RAILROAD.

A standard-gage railroad approximately 4½ miles long has been estimated from Red Bluff to the dam site.

UNIT COSTS OF MATERIALS.

Cement.—This is assumed to cost $2.70 a barrel at the dam site, based on the following:

Cost per barrel at Tolenas, Calif	$3.00
Freight to Red Bluff	.16
Freight, Red Bluff to site	.04

Handling	$0.30
Gross	3.50
Less 3 sacks returned at $0.25	.75
Less discount	.05
	2.70

The above freight charge of $0.16 per barrel is based on the assumption that the shipments would be routed over the land-grant road on the east side of the river. If routed over the line on the west side of river the freight charge would be $0.51 per barrel and the cost correspondingly increased.

Sand and gravel.—These materials will be obtained from pits 3 to 4 miles distant, located on the railroad. The assumed cost is $0.90 per cubic yard.

Concrete.—The following tables show the concrete costs assumed for the estimates:

Gravity dam sections, Types I, II, and III (1:3:6 mix):	
Cement, 1.05 barrels, at $2.70	$2.84
Sand, 0.44 cubic yard, at $0.90	.40
Gravel, 0.89 cubic yard, at $0.90	.80
Forms, 1 cubic yard, at $1	1.00
Mixing and placing 1 cubic yard, at $1.50	1.50
Plant depreciation, 1 cubic yard, at $1	1.00
Total	7.54
Used	7.50
Deep cut-off and fore apron, Types I, II, and III (1:3:6 mix):	
Cement, 1.05 barrels, at $2.70	2.84
Sand, 0.44 cubic yard, at $0.90	.40
Gravel, 0.89 cubic yard, at $0.90	.80
Mixing and placing, 1 cubic yard, at $2	2.00
Plant depreciation, 1 cubic yard, at $1	1.00
Total	7.04
Used	7.00
Power-house section, Types I, II, and III (1:3:6 mix):	
Cement, 1.05 barrels, at $2.70	2.84
Sand, 0.44 cubic yards, at $0.90	.40
Gravel, 0.89 cubic yards, at $0.90	.80
Reinforcing steel, 6.4 pounds, at $0.08	.51
Forms, 1 cubic yard, at $1.20	1.20
Mixing and placing, 1 cubic yard, at $1.50	1.50
Plant depreciation, 1 cubic yard, at $1	1.00
Total	8.25

Slope lining (fore apron), Types I, II, and III (1:3:6 mix):	
Cement, 1.05 barrels, at $2.70	$2.84
Sand, 0.44 cubic yards, at $0.90	.40
Gravel, 0.89 cubic yards, at $0.90	.80
Reinforcing steel, 60 pounds, at $0.08	4.80
Forms, 1 cubic yard, at $3	3.00
Mixing and placing, 1 cubic yard at $2	2.00
Plant depreciation, 1 cubic yard, at $1	1.00
Total	14.84
Used	15.00
Trash rack (power house), Types I, II, and III (1:2½:5 mix):	
Cement, 1.24 barrels, at $2.70	3.35
Sand, 0.44 cubic yard, at $0.90	.40
Gravel, 0.87 cubic yard, at $0.90	.78
Reinforcing steel, 135 pounds, at $0.08	10.80
Forms, 1 cubic yard, at $10	10.00
Mixing and placing, 1 cubic yard, at $3	3.00
Plant depreciation, 1 cubic yard, at $1	1.00
Total	29.33
Used	29.25
Siphon head (flood-control section), Types I, II, and III (1:2½:5 mix):	
Cement, 1.25 barrels, at $2.70	3.35
Sand, 0.44 cubic yard, at $0.90	.40
Gravel, 0.87 cubic yard, at $0.90	.78
Reinforcing steel, 135 pounds, at $0.08	10.80
Forms, 1 cubic yard, at $7.50	7.50
Mixing and placing, 1 cubic yard, at $3	3.00
Plant depreciation, 1 cubic yard, at $1	1.00
Total	26.88
Used	27.00
Flood-control section, Types I, II, and III, Ogee spillway, Type I and Rollway Types II and III (1:3:6 mix):	
Cement, 1.05 barrels, at $2.70	2.84
Sand, 0.44 cubic yard, at $0.90	.40
Gravel, 0.89 cubic yard, at $0.90	.80
Forms, 1 cubic yard, at $1.50	1.50
Mixing and placing, 1 cubic yard, at $1.50	1.50
Plant depreciation, 1 cubic yard, at $1	1.00
Total	8.04
Used	8.00
Deck, parapet, floor, and floor beam, Type II (1:2:4 mix):	
Cement, 1.5 barrels, at $2.70	4.05
Sand, 0.42 cubic yard, at $0.90	.38
Gravel, 0.84 cubic yard, at $0.90	.76
Reinforcing steel, 113 pounds, at $0.08	9.04
Forms, 1 cubic yard, at $3	3.00

Deck, parapet, floor, and floor beam, Type II (1:2:4 mix)—Continued.	
Mixing and placing, 1 cubic yard, at $3.75	$3.75
Plant depreciation, 1 cubic yard, at $1	1.00
Total	21.98
Used	22.00
Buttresses and struts, Type II (1:3:6 mix):	
Cement, 1.05 barrels, at $2.70	2.84
Sand, 0.44 cubic yard, at $0.90	.40
Gravel, 0.89 cubic yard, at $0.90	.80
Reinforcing steel, 35 pounds, at $0.08	2.80
Forms, 1 cubic yard, at $2.25	2.25
Mixing and placing, 1 cubic yard, at $2.50	2.50
Plant depreciation, 1 cubic yard, at $1	1.00
Total	12.59
Used	12.50
Core wall, Type III (1:2½:5 mix):	
Cement, 1.24 barrels, at $2.70	3.35
Sand, 0.44 cubic yard, at $0.90	.40
Gravel, 0.87 cubic yard, at $0.90	.78
Reinforcing steel, 20 pounds, at $0.08	1.60
Forms, 1 cubic yard, at $1	1.00
Mixing and placing, 1 cubic yard, at $2.50	2.50
Plant depreciation, 1 cubic yard, at $1	1.00
Total	10.63
Used	10.75
Abutments, Type III (1.2½:5 mix, formed):	
Cement, 1.24 barrels, at $2.70	3.35
Sand, 0.44 cubic yard, at $0.90	.40
Gravel, 0.87 cubic yard, at $0.90	.78
Forms, 1 cubic yard, at $3	3.00
Reinforcing steel, 135 pounds, at $0.08	10.80
Mixing and placing, 1 cubic yard, at $3	3.00
Plant depreciation, 1 cubic yard, at $1	1.00
Total	22.33
Used	22.50
Abutments, Type III (1:2½:5 mix, unformed):	
Cement, 1.24 barrels, at $2.70	3.35
Sand, 0.44 cubic yard, at $0.90	.40
Gravel, 0.87 cubic yard, at $0.90	.78
Reinforcing steel, 135 pounds, at $0.08	10.80
Mixing and placing, 1 cubic yard, at $1.50	1.50
Plant depreciation, 1 cubic yard, at $1	1.00
Total	17.83
Used	18.00

PRELIMINARY ESTIMATES.

Type I, Gravity dam.

Top of dam elevation, 410.5. Normal water supply elevation 392.5. Total capacity, 775,100 acre-feet. Net capacity, 640,500 acre-feet above elevation 340.

[See Exhibits K, L, M, and N.]

Item.	Quantity.	Unit cost.	Total cost.	Summary.
Cofferdams:				
Timber for crib in place	4,000 M. B. M.	$78.00	$312,000	
Iron drift bolts, etc	53,400 pounds	.10	5,340	
Rock and gravel filling	93,000 cubic yards	1.50	139,500	
Pumping and washouts, estimated			73,160	
Total, cofferdams				$530,000
Gravity section (sta. 1+70 to 13+33):				
Excavation—				
Class II for base of dam	133,000 cubic yards	1.50	199,500	
Class II for deep cut-off	4,080 cubic yards	7.50	30,600	
Total, excavation				230,100
Concrete dam section (1:3:6 mix)	188,000 cubic yards	7.50		1,410,000
Parapets	2,326 linear feet	10.00		23,260
Concrete deep cut-off (1:3:6 mix)	4,080 cubic yards	7.00		28,560
Total gravity section (sta. 1+70 to 13+33)				1,691,920
Powerhouse section (sta. 13+33 to 15+33):				
Excavation, Class II	70,400 cubic yards	1.50		105,600
Concrete dam section (1:3:6 mix)	93,600 cubic yards	8.25		772,200
Concrete fore apron (1:3:6 mix)	8,150 cubic yards	7.00		57,050
Concrete slope lining (1:3:6 mix)	1,850 cubic yards	15.00		27,750
Gates, 5, 16 by 16 feet, Stoney—				
Structural steel	170,000 pounds	.15	25,500	
Gate stems, including couplings and guides	46,500 pounds	.25	11,625	
Roller trains	41,600 pounds	.35	14,560	
Castings	14,000 pounds	.20	2,800	
Bolts, miscelleneous, etc	13,400 pounds	.10	1,340	
Gate stands, 5 sets	15,000 pounds	.35	5,250	
Freight	300,500 pounds	.01	3,005	
Installation and painting	do	.02	6,010	
Gates in place	5	14,020.00	70,090	70,100
Trash rack metal—				
Structural steel in place	404,000 pounds	.10	40,400	
Cast iron	6,000 pounds	.10	600	
Raking device	Lump sum		5,000	
Trash rack concrete (1:2½:5 mix)	1,680 cubic yards	29.25		46,000
Parapets	400 linear feet	10.00	4,000	49,140
Buildings (electrical division estimate)				4,000
Machinery (electrical division estimate)				275,000
Total, powerhouse section (sta. 13+33 to 15+33)				1,800,000
Flood-control section (sta. 15+33 to 21+00):				3,206,840
Excavation, Class II	155,000 cubic yards	1.50		232,500
Concrete siphon head (1:2½:5 mix)	17,600 cubic yards	27.00		475,200
Concrete dam (1:3:6 mix)	233,000 cubic yards	8.00		1,864,000
Parapets	567 linear feet	10.00		5,670
Handrail	2,750 linear feet	3.00		8,250
Concrete fore apron, 1:3:6 mix	48,100 cubic yards	7.00		336,700
Concrete slope lining, 1:3:6 mix	2,190 cubic yards	15.00		32,850
Gates, 27, 12 by 19 feet, Stoney—				
Structural steel	856,000 pounds	.15	128,400	
Stems, guides and couplings	213,000 pounds	.25	53,250	
Roller trains	210,000 pounds	.35	73,500	
Castings	72,700 pounds	.20	14,540	
Bolts and miscellaneous	67,800 pounds	.10	6,780	
Stands, 27 sets	56,500 pounds	.35	19,775	
10-inch valves	27	250.00	6,750	
10-inch pipe and fittings	13,000 pounds	.20	2,600	
Freight	1,489,000 pounds	.01	14,890	
Installation and painting	do	.02	29,780	
Stoney gates in place	27	12,970.00	350,265	350,190

Type I, Gravity dam—Continued.

Item.	Quantity.	Unit cost.	Total cost.	Summary.
Flood-control section (sta. 15+33 to 21+00)—Continued.				
Gates, 27, 10 by 12 foot drum gates—				
Structural steel and cast iron	2,210,000 pounds	$0.15	$331,500	
10-inch pipe and fittings	254,000 pounds	.20	50,800	
10-inch valves	54	250.00	13,500	
Freight	2,464,000 pounds	.01	24,640	
Installation and painting	do	.04½	110,880	
			531,320	
Drum gates in place	27	19,680.00		$531,360
Total, flood control section (sta. 15+33 to 21+00)				3,836,720
Gravity section (sta. 21+00 to 40+00):				
Excavation—				
Class II for base of dam	120,000 cubic yards	1.50	180,000	
Class II for deep cut-off	12,100 cubic yards	7.50	90,750	
Total, excavation				270,750
Concrete dam, 1:3:6 mix	160,000 cubic yards	7.50		1,200,000
Concrete deep cut-off, 1:3:6 mix	12,100 cubic yards	7.00		84,700
Parapets	3,800 linear feet	10.00		38,000
Total, gravity section (sta. 21+00 to 40+00)				1,593,450
Ogee spillway section (sta. 40+00 to 50+00):				
Excavation—				
Class II, base of dam and discharge channel	43,500 cubic yards	1.50	65,250	
Class II, deep cut-off	8,000 cubic yards	7.50	60,000	
Total, excavation				125,250
Concrete, Ogee section, 1:3:6 mix	16,600 cubic yards	8.00		132,800
Concrete deep cut-off, 1:3:6 mix	8,000 cubic yards	7.00		56,000
Total, Ogee spillway section (sta. 40+00 to 50+00)				314,050
Gravity section (sta. 50+00 to 53+45):				
Excavation—				
Class II, deep cut-off	1,540 cubic yards	7.50	11,550	
Class II, for base of dam	500 cubic yards	1.50	750	
Total, excavation				12,300
Concrete dam, 1:3:6 mix	1,420 cubic yards	7.50		10,650
Concrete deep cut-off	1,540 cubic yards	7.00		10,780
Parapets	690 linear feet	10.00		6,900
Total, gravity section (sta. 50+00 to 53+45)				40,630
Earth blanket (upstream from power house and flood-control sections), hydraulic earth fill	171,000 cubic yards	.50	85,500	85,500
Grouting (sta. 8+60 to 26+50):				
Drilling	8,000 linear feet	1.50	12,000	
Grouting	do	1.50	12,000	
Total, grouting				24,000
Drain holes (below grout holes), drilling	9,000 linear feet	1.50		13,500
Lamp posts	80	50.00		4,000
Railroad construction and equipment	4 miles	40,000.00	160,000	
Do	½ mile	70,000.00	35,000	
Total, railroad				195,000
Construction camp				240,000
Permanent camp:				
Cottages	14		44,000	
Water, sewer, and light systems			5,000	
Miscellaneous improvements			5,000	
Total, permanent camp				54,000
Finishing and cleaning up				60,000
Estimated cost of dam				11,889,610
Contingencies, 10 per cent				1,188,961
Administrative and engineering, 15 per cent				1,783,442
Grand total (exclusive of right of way)				14,862,013

Type II, Combination gravity and buttress dam.

Top of dam elevation, 410.5. Total capacity, 775,100 acre-feet. Normal water-supply elevation, 392.5. Capacity 640,500 acre-feet above elevation 340.

[See Exhibits K, L, M, and N.]

Item.	Quantity.	Unit cost.	Total cost.	Summary.
Cofferdams (see estimate for Type I)				$530,000
Buttress section (sta. 1+70 to 10+60):				
Excavation—				
Class II, for base of dam	67,500 cubic yards	$1.50	$101,250	
Class II, for deep cut-off	4,080 cubic yards	7.50	30,600	
Total, excavation				131,850
Concrete, deck, parapet, floor, and floor beams, 1:2:4 mix	9,900 cubic yards	22.00		217,800
Concrete, buttresses and struts, 1:3:6 mix	22,300 cubic yards	12.50		278,750
Concrete, deep cut-off, 1:3:6 mix	4,080 cubic yards	7.00		28,560
Handrail	890 linear feet	3.00		2,670
Total, buttress section (sta. 1+70 to 10+60)				659,630
Gravity section (sta. 10+60 to 13+33):				
Excavation, Class II, for base of dam	65,500 cubic yards	1.50		98,250
Concrete, 1:3:6 mix	108,000 cubic yards	7.60		810,000
Parapets	546 linear feet	10.00		5,460
Total, gravity section (sta. 10+60 to 13+33)				913,710
Power-house section (sta. 13+33 to 15+33) (see estimate for Type I)				3,206,840
Flood-control section (sta. 15+33 to 21+00) (see estimate for Type I)				3,836,720
Gravity section (sta. 21+00 to 21+45):				
Excavation, Class II, for base of dam	3,530 cubic yards	1.50		5,295
Concrete, 1:3:6 mix, dam	14,400 cubic yards	10.00		108,000
Parapets	90 linear feet	10.00		900
Total, gravity section (sta. 21+00 to 21+45)				114,195
Buttress section (sta. 21+45 to 40+00):				
Excavation—				
Class II, for base of dam	116,000 cubic yards	1.50	174,000	
Class II, for deep cut-off	12,100 cubic yards	7.50	90,750	
Total, excavation				264,750
Concrete, deck, parapets, floor, floor beams, 1:2:4 mix	15,800 cubic yards	22.00		347,600
Concrete, buttresses and struts, 1:3:6 mix	34,400 cubic yards	12.50		430,000
Concrete, deep cut-off, 1:3:6 mix	12,100 cubic yards	7.00		84,700
Handrail	1,855 linear feet	3.00		5,565
Total, buttress section (sta. 21+45 to 40+00)				1,132,61[illegible]
Ogee buttress spillway (sta. 40+00 to 50+00):				
Excavation—				
Class II, base of dam and discharge channel	43,500 cubic yards	1.50	65,250	
Class II, deep cut-off	8,000 cubic yards	7.50	60,000	
Total excavation				125,250
Concrete, decks, 1:2:4 mix	3,820 cubic yards	22.00		84,040
Concrete, buttresses, 1:3:6 mix	1,040 cubic yards	12.50		13,000
Concrete, rollway, 1:3:6 mix	4,190 cubic yards	8.00		33,520
Concrete, deep cut-off, 1:3:6 mix	8,000 cubic yards	7.00		56,000
Total, Ogee buttress spillway (sta. 40+00 to 50+00)				311,810

Type II, Combination gravity and buttress dam—Continued.

Item.	Quantity.	Unit cost.	Total cost.	Summary.
Buttress section (sta. 50+00 to 53+45):				
Excavation—				
Class II, for base of dam	500 cubic yards	$1.50	$750	
Class II, for deep cut-off	1,540 cubic yards	7.50	11,550	
Total, excavation				$12,300
Concrete, deck, parapet, floor, and floor beams, 1:2:4 mix	330 cubic yards	22.00		7,260
Concrete, deep cut-off, 1:3:6 mix	1,540 cubic yards	7.00		10,780
Handrail	345 linear feet	3.00		1,035
Total, buttress section (sta. 50+00 to 53+45)				31,375
Earth blanket (upstream from power-house and flood-control sections), hydraulic earth fill	171,000 cubic yards	0.50		85,500
Grouting (sta. 8+60 to 26+50):				
Drilling	8,000 linear feet	1.50	12,000	
Grouting	do	1.50	12,000	
Total grouting				24,000
Drain holes (below grout), drilling	9,000 linear feet	1.50		13,500
Lamp posts	80	50.00		4,000
Railroad construction and equipment (see estimate, Type I, for details)				195,000
Construction camp				240,000
Permanent camp (see estimate, Type I, for details)				54,000
Finishing and cleaning up				60,000
Estimated cost of dam				11,416,270
Contingencies, 10 per cent				1,141,627
Administrative and engineering, 15 per cent				1,712,441
Grand total (exclusive of right of way)				14,270,338

Type III, Combination gravity and earth-fill dam.

Top of dam elevation, 410.5. Normal water-supply elevation, 392.5. Total capacity, 775,100 acre-feet. Capacity 640,500 acre-feet above elevation 340.

[No drawings included; see p. 23.]

Item.	Quantity.	Unit cost.	Total cost.	Summary.
Cofferdams (see estimate for Type I)				$530,000
Earth-fill section (sta. 1+70 to 10+60):				
Excavation—				
Class II, stripping	16,700 cubic yards	$1.50	$25,050	
Class II, deep cut-off	6,300 cubic yards	7.50	47,250	
Total, excavation				72,300
Embankment—				
6-inch layers moistened and rolled	594,000 cubic yards	.65		386,100
Concrete, 1:3:6 mix—				
Core wall	5,600 cubic yards	10.75	60,200	
Deep cut-off	6,300 cubic yards	7.00	44,100	
Total, concrete				104,300
Total, Earth-fill section (sta. 1+70 to 10+60)				562,700
Concrete abutment (sta. 10+60):				
Excavation, Class II	51,800 cubic yards	1.50		77,700
Concrete, 1:2½:5 mix—				
Formed	9,910 cubic yards	22.50	222,975	
Unformed	6,440 cubic yards	18.00	115,920	
Total, concrete				338,895
Total, concrete abutment (sta. 10+60)				416,595

Type III, Combination gravity and earth-fill dam—Continued.

Item.	Quantity.	Unit cost.	Total cost.	Summary.
Gravity section (sta. 10+60 to 13+33) (see estimate, Type II)				$913,710
Power-house section (sta. 13+33 to 15+33) (see estimate, Type I				3,206,840
Flood-control section (sta, 15+33 to 21+00) (see estimate, Type I)				3,836,720
Gravity section (sta. 21+00 to 23+75):				
Excavation—				
Class II, base of dam	43,500 cubic yards	$1.50	$65,250	
Class II, deep cut-off	1,100 cubic yards	7.50	8,250	
Total, excavation				73,500
Concrete, 1:3:6 mix	67,700 cubic yards	7.50		507,750
Parapets	550 linear feet	10.00		5,500
Total, gravity section (sta. 21+00 to 23+75)				586,750
Concrete abutment (sta. 23+75):				
Excavation, Class II	56,200 cubic yards	1.50		84,300
Concrete, 1:2½:5 mix—				
Formed	10,800 cubic yards	22.50	243,000	
Unformed	6,990 cubic yards	18.00	125,820	
Total, concrete				368,820
Total, concrete abutment (sta. 23+75)				453,120
Earth-fill section (sta. 23+75 to 40+00):				
Excavation—				
Class II, stripping	21,000 cubic yards	1.50	31,500	
Class II, deep cut-off	11,900 cubic yards	7.50	89,250	
Total excavation				120,750
Embankment, 6-inch layers, moistened and rolled	494,000 cubic yards	.65		321,100
Concrete, 1:3:6 mix—				
Deep cut-off	11,900 cubic yards	7.00	83,300	
Core wall	4,840 cubic yards	10.75	52,030	
Total, concrete				135,330
Total, earth-fill section (sta. 23+75 to 40+00)				577,180
Concrete abutment (sta. 40+00):				
Excavation, Class II	1,300 cubic yards	1.50		1,950
Concrete, 1:2½:5 mix—				
Formed	400 cubic yards	22.50	9,000	
Unformed	170 cubic yards	18.00	3,060	
Total, concrete				12,060
Total, concrete abutment (sta. 40+00)				14,010
Ogee buttress spillway (sta. 40+00 to 50+00) (see estimate for Type II)				311,810
Concrete abutment (sta. 50+00):				
Excavation, Class II	6,000 cubic yards	1.50		9,000
Concrete, 1:2½:5 mix—				
Formed	400 cubic yards	22.50	9,000	
Unformed	170 cubic yards	18.00	3,060	
Total concrete				12,060
Total, concrete abutment (sta. 50+00)				21,060
Earth-fill section (sta. 50+00 to 53+45):				
Excavation—				
Class II, stripping	1,140 cubic yards	1.50	1,710	
Class II, deep cut-off	1,540 cubic yards	7.50	11,550	
Total, excavation				13,260
Embankment, 6-inch layers, moistened and rolled	13,600 cubic yards	.65		8,840

Type III, Combination gravity and earth-fill dam—Continued.

Item.	Quantity.	Unit cost.	Total cost.	Summary.
Earth-fill section—Continued.				
Concrete, 1:3:6 mix—				
Deep cut-off	1,540 cubic yards	$7.00	$10,780	
Core wall	136 cubic yards	10.75	1,462	
Total, concrete				$12,242
Total, earth-fill section				34,342
Earth blanket (upstream from power house and flood-control sections), hydraulic earth-fill	171,000 cubic yards	.50		85,500
Grouting (sta. 10+60 to 23:75):				
Drilling	5,900 linear feet	1.50	8,850	
Grouting	do	1.50	8,850	
Total, grouting				17,700
Drain holes (below grout), drilling	6,600 linear feet	1.50		9,900
Lamp-posts (see estimate, Type I)				4,000
Railroad construction and equipment (see estimate, Type I)				195,000
Construction camp (see estimate, Type I)				240,000
Permanent camp (see estimate, Type I)				54,000
Finishing and cleaning up				60,000
Estimated cost of dam				12,130,937
Contingencies, 10 per cent				1,213,094
Administration and engineering, 15 per cent				1,819,641
Grand total (exclusive of right of way)				15,163,672

Reservoir, main canal, and lateral system.

Reservoir lands:		
Former estimate	$2,034,000	
Increased values	321,500	
Additional land, 1,780 acres, at $25	44,500	
Road construction, etc	200,000	
		$2,600,000
Bend embankment:[1]		
Earth-fill, 240,000 cubic yards, at $0.75	180,000	
Lose rock paving, 16,000 cubic yards, at $4	64,000	
6-inch layer of gravel, 8,000 cubic yards, at $1	8,000	
Concrete, 10,000 cubic yards, at $16	160,000	
	412,000	
Contingencies and overhead expenses, 25 per cent	103,000	
		515,000
Main canal:		
Headworks at Bend embankment (four 8-foot tubes)—		
Excavation, 16,000 cubic yards, at $0.75	12,000	
Concrete—		
330 cubic yards, at $17	5,610	
2,600 cubic yards, at $18	46,800	
810 cubic yards, at $19	15,390	
470 cubic yards, at $20	9,400	
Bridge steel, 14,000 pounds, at $0.12	1,680	
Railing and floor	500	
Gates and hoists, 24, at $2,000	48,000	
		139,380

[1] Quantities from 1914 report. Unit prices revised.

Main canal—Continued.		
Right of way, 1,003 acres—		
90 acres, at $20	$1,800	
522 acres, at $50	26,100	
236 acres, at $75	17,700	
99 acres, at $80	7,920	
56 acres, at $400	22,400	
		$75,920
Excavation—		
300,000 cubic yards, at $0.75	225,000	
7,210,200 cubic yards, at $0.30	2,163,060	
		2,388,060
Extra for preparing embankments, 3,411,400 cubic yards, at $0.15		512,000
Concrete lining, 2,034,400 square yards, at $1.10		2,237,840
Concrete culverts—		
9 culverts, 24-inch concrete pipe	$1,755	
1 culvert, 4 by 5 foot concrete box	2,640	
1 culvert, 2, 4 by 6 foot concrete boxes	4,800	
2 culverts, 3, 4 by 6 foot concrete boxes	15,900	
2 culverts, 4, 4 by 6 foot concrete boxes	18,800	
1 culvert, 5, 4 by 6 foot concrete boxes	11,340	
1 culvert, 6, 4 by 6 foot concrete boxes	14,400	
1 culvert, 1, 5 by 8 foot concrete box	5,000	
2 culverts, 1, 5 by 10 foot concrete box	5,200	
6 culverts, 2, 5 by 10 foot concrete boxes	52,800	
3 culverts, 3, 5 by 10 foot concrete boxes	34,400	
2 culverts, 4, 5 by 10 foot concrete boxes	34,000	
1 culvert, 5, 5 by 10 foot concrete boxes	16,600	
1 culvert, 5, 6 by 10 foot concrete boxes	18,000	
2 culverts, 6, 6 by 10 foot concrete boxes	42,000	
1 culvert, 1, 10-foot concrete arch	4,000	
3 culverts, 2, 10-foot concrete arches	30,600	
1 culvert, 3, 10-foot concrete arches	9,800	
1 culvert, 4, 10-foot concrete arches	14,800	
1 culvert, 6, 10-foot concrete arches	18,200	
3 culverts, 3, 12-foot concrete arches	44,300	
2 culverts, 4, 12-foot concrete arches	46,600	
1 culvert, 5, 12-foot concrete arches	10,000	
5 culverts, 6, 12-foot concrete arches	127,800	
2 culverts, 7, 12-foot concrete arches	77,000	
2 culverts, 10, 12-foot concrete arches	80,000	
1 culvert, 14, 12-foot concrete arches	70,000	
		810,735
Concrete aqueducts—		
Station 58, 200 linear feet, at $284	$56,800	
Station 112, 400 linear feet, at $322	128,800	
Blue Tent Creek, 1,150 linear feet, at $309	355,350	
Dibble Creek, 1,650 linear feet, at $322	531,300	
Reeds Creek, 1,500 linear feet, at $309	463,500	
Redbank Creek, 550 linear feet, at $260	143,000	
Elder Creek, 400 linear feet, at $222	88,800	
		1,767,550

Main canal—Continued.		
Concrete siphons—		
Thomas Creek, 600 linear feet, at $228	$136,800	
Rice Creek, 250 linear feet, at $228	57,000	
Stony Creek, 2,700 linear feet, at $183	494,100	
		$687,900
Drops, 3		13,000
Wasteways, 13		51,560
Turnouts		90,590
Bridges—		
35, at $2,200	$77,000	
17, at $1,116	18,972	
5, at $760	3,800	
8, at $376	3,008	
4, at $180	720	
		103,500
Miscellaneous structures		25,000
Buildings for canal system		50,000
Telephone system		26,000
Fencing, 69.5 miles, at $600		41,700
		9,020,735
Contingencies and overhead expense, 25 per cent		2,255,184
Total cost of main canal		11,275,919
Lateral system:		
225,000 acres, at $37		8,325,000

Summary of cost of Iron Canyon project.

Storage dam, including power development (Type No. 1 dam)	$14,862,013
Reservoir lands and marginal roads	2,600,000
Bend embankment	515,000
Main canal	11,275,919
Lateral system	8,325,000
Total estimated cost of project	37,577,932
Less credit for power plant (see p. 21)	7,500,000
Net cost for irrigation	30,077,932
Cost per acre for a 225,000-acre project	$133.70

INTEREST CHARGES.

The estimate has been made without considering interest charges. Funds for construction would be required in about the following proportions for each year:

	Per cent.		Per cent.
First year	5	Sixth year	15
Second year	7	Seventh year	10
Third year	10	Eighth year	6
Fourth year	20	Ninth year	4
Fifth year	20	Tenth year	3

If interest charges accumulate from the several dates when the funds are made available for expenditure, at the rate of progress

assumed above at the end of the tenth year the total interest charge would be equivalent to six years' interest on the whole cost.

In making this estimate of cost the former report and estimate have been used as a basis or starting point, and changes and additions were made as the present conditions seemed to require. The designs of structures and of the canal have been altered and the unit prices generally increased to agree with present market conditions.

The increased value of some of the reservoir lands results from the recent construction of the Anderson-Cottonwood irrigation system, covering a district which extends into the proposed Iron Canyon reservoir, affecting about 7,680 acres lying below the 400-foot contour. About 1,780 acres additional land is required by reason of using the lower dam site.

The designs and estimates for the storage dam were made in the office of the chief engineer, United States Reclamation Service, at Denver. The cost of headworks at Bend embankment has been estimated on the basis of four inlet tubes 8 feet in diameter, instead of three tubes as proposed in 1914 report, on account of increased canal capacity. Right-of-way prices for the canal have been assumed at $20 per acre for hilly pasture, $50 to $80 for grain land not irrigated, and $400 for fully irrigated land, as in the Orland project.

Excavation on the main canal is assumed to be all earth except that portion north of Blue Tent Creek, where a large percentage of soft rock or tuff is found. The average or unclassified price for this portion is assumed at 75 cents per cubic yard. For the concrete siphons at Thomas and Rice creeks four tubes 9.6 feet in diameter are proposed. The Stony Creek siphon requires three tubes of 9.6 feet diameter.

CANAL LINING.

The estimated cost of the lateral system is based on records of recent construction on the Orland project. Practically permanent construction is proposed for all structures. Wood is allowed for bridge decks and a few minor details. If the lining of the main and lateral canals should be postponed until some future time when the irrigable area has been fully developed and lining becomes necessary for conservation of water, the first cost of the project would be reduced from the above estimate by at least $6,400,000, or about $28.40 per acre.

The canal survey must be regarded as a preliminary rather than a final location. The available funds did not permit of a thorough investigation such as a project of this magnitude would warrant. The estimate is based on the present survey and it is probable that a complete and final location would result in a considerable reduction of quantities.

SUMMARY.

The foregoing discussion and the calculations involved therein are based on a proposed project of 225,000 acres with the storage dam located at the lower site. The plan includes the storage of 640,000 acre-feet and the use of 288,125 acre-feet per annum additional from the natural flow. By taking into account the return waters and accretions below Iron Canyon as materially increasing the supply for water users having prior rights the area of this project might be considerably extended. Investigations by the State Department of Engineering during the summer of 1919 indicated the occurrence of considerable return flow between Red Bluff and Knights Landing. When other large areas in this valley have been brought under irrigation the return flow may be expected to be much greater, but the amount can not be closely predicted.

If on account of return waters, or other reason, the use of water from the Sacramento for the Iron Canyon project were permitted above a limit of 5,000 second-feet natural flow in May, June, July, and August, instead of 6,000 second-feet as herein assumed, the supply would be sufficient for 255,000 acres, with about the same deficiencies as given on page 14. The extra acreage would be reached by a main canal of larger capacity and an extension of the canal system, but without adding to the cost of dam and reservoir, thus effecting a reduction in the cost per acre on this project. The power production at the dam, however, would be diminished at times, but the minimum of 29,000 horsepower stated on page 21 would not be lowered.

PROPOSED RESERVOIRS ON REDBANK, ELDER, AND THOMAS CREEKS.

These creeks head in the mountains and foothills west of the Sacramento Valley and flow eastward to the Sacramento River through the irrigable area of the Iron Canyon project. There are possibilities of reservoirs on these streams and areas on which their waters could be used to the west of the line of the Iron Canyon Canal and outside of the irrigable area of that project.

SECONDARY RESERVOIRS.

Definite information as to run-off and reservoir capacity is lacking and the feasibility and cost of these several projects can not be determined until such information is available. If these sources are to be developed by storage, their waters could be used either on lands to the west of the Iron Canyon Canal or in connection with that canal on lower lands as may appear best on further investigation. As the

drainage areas are small the water supply is likely to be very irregular and uncertain and for this reason it may be found best to use them in connection with the larger system.

PERSONNEL.

The work of the United States Reclamation Service in these investigations was performed under the general direction of F. E. Weymouth, chief engineer, by H. J. Gault, engineer, with A. M. Jordan, diamond-drill foreman. E. T. Eriksen, engineer, assisted with the office work. The part done by the State was under the supervision of W. F. McClure, State Engineer of California; S. W. Curtis, assistant engineer; and J. E. Tempest, chief of field party. The executive committee of the Iron Canyon Project Association cooperating under this agreement was Hon. John F. Ellison, W. A. Beard, A. L. Conard, and T. H. Ramsey.

COST OF INVESTIGATIONS.

Below is given a summary of the costs incurred in this investigation:

Reconnaissance	$611.31
Trial lines	62.50
Estimates	3,380.53
Test borings, etc	8,701.19
Test pits	211.20
Tunnels and shafts	281.07
Subtotal	13,247.80
Superintendence and accounts	553.71
Engineering and inspection	3,344.34
General expense	2,236.78
Grand total	19,382.63

Estimated amounts included in the foregoing are:

Board of engineers expense	$850.00
Publication of report	500.00
Equipment depreciation	100.00
Denver office designing:	
May	516.72
June	235.45
Homer Hamlin, May expense	50.00

CONCLUSIONS AND RECOMMENDATIONS.

1. The following conclusions and recommendations resulting from the cooperative investigation of the Iron Canyon project in California are agreed upon by the engineer of the United States Recla-

mation Service in charge of the work and the State Engineer of California.

2. The present investigations have added much to the data previously had on the project. A more satisfactory dam site in Iron Canyon has been found, the main canal has been approximately located, the estimates of cost were revised, and studies of the water supply and other subjects bearing on the feasibility of the project have been brought up to date, taking into account the additional record of river flow, recent appropriations of water, and new conditions generally.

3. While the plan proposed would perhaps not be seriously detrimental to navigation at any time, neither would it be of benefit except in times of high water when flood peaks might be reduced and driftwood retained by the reservoir. It does not appear to be practicable in connection with the proposed Iron Canyon irrigation project to provide any extra storage for the benefit of navigation.

4. The measure of flood control which can be effected by the proposed manner of operating the reservoir is considerable, and while the primary function of the reservoir is to provide storage for irrigation it is believed that by the proper regulation of the gates a very large degree of flood protection can be provided without detriment to irrigation interests.

5. The power plant would be a valuable accessory to the dam, worth much more than its cost, and its inclusion should very materially reduce the irrigation cost.

6. The physical requirements for feasibility of the project are present, and if the cost is not prohibitive at the present time the project is also financially feasible. The estimated cost of about $130 per acre after deducting credit for power plant, if payable in installments running through 20 to 40 years, is in our opinion not more than the landowners could well afford to pay under present market conditions, provided the item of interest during construction and early years of development is not large or is absent and land prices are held within reasonable limits. Some classification and selection of lands may become necessary, to exclude tracts if there be any which by reason of poor soil or other handicap obviously could not bear the cost.

7. The assumed conditions and the estimates of cost seem to be conservative, and there is a chance that the cost per acre may be reduced by favorable contingencies, some of which are here mentioned.

8. If on account of return waters or for any other reason the limits above which storage and use are to be permitted for this project may be brought below those herein assumed, the water sup-

ply available would be thereby increased and the acreage could be extended accordingly.

9. An increase in the duty of water, which may follow from a careful classification of the soils, consideration of diversified crops, and the prevention of part of the large canal losses assumed would permit a still further extension of the acreage.

10. As it would be a number of years before the whole area would reach its full agricultural development it may be possible in the meantime to use some of the water acquired for this project elsewhere and thus produce a revenue.

11. It may be found more profitable to sell electric power at the switchboard than to lease the plant on the basis of the value credited in the estimates. Present indications are that the demand for electric power will continue to increase, and the power feature of this project might in time prove to be much more profitable than is indicated by the value credited.

12. The final location of the main canal line may be expected to diminish the quantities of excavation in the estimate. Prices of materials and labor have nearly doubled in the past few years, but there is reason to expect that the general rise may have about reached its limit and that there may be a gradual decline effective to some extent before the bulk of the purchases is made for this construction, resulting in a saving in cost of project.

13. On the other hand, if prices should continue to advance or if unexpected hazards should be encountered in construction, such events would tend to counteract or offset the possible advantages mentioned above.

14. There is need of further investigations to select the areas to be irrigated, since there is the possibility of many alternative plans. It may be found advisable to build a larger and longer canal than herein proposed on the east side to reach lands as far as Chico or farther. The proposed secondary reservoirs on Redbank, Elder, and Thomas creeks should be investigated to ascertain whether they could be advantageously used in combination with the Iron Canyon project to increase the irrigable area and where the additional lands may be most profitably reached. Another possible variation in the plan would be to release stored water at Iron Canyon into the river channel to be diverted or pumped out at points downstream. Still other plans may be suggested that should be investigated.

15. In each case the investigations should locate definitely and in detail the lands to be included in the project, and the proper duty of water to be allowed should be determined from an investigation of the soils. Some combination of the various possible plans may be

found by which the cost per acre would be less than is estimated in this report and equally good or better lands served.

H. J. GAULT,
Engineer, U. S. Reclamation Service.
W. F. MCCLURE,
State Engineer of California.

Approved:
A. P. DAVIS,
Director, U. S. Reclamation Service.

APPENDIX No. 1

REPORT OF HOMER HAMLIN, CONSULTING ENGINEER, UPON GEOLOGICAL EXAMINATION OF IRON CANYON DAM AND RESERVOIR SITE

LOS ANGELES, CALIFORNIA
DECEMBER 12, 1919

DECEMBER 12, 1919.

From: Homer Hamlin, consulting engineer, 1103 Central Building, Los Angeles, Calif.

To: Chief of Construction, Denver, Colo.

Subject: Iron Canyon Dam and Reservoir site.

1. In compliance with your request of June 19, 1919, a report upon the geological examination of Iron Canyon Dam and Reservoir site, California, is herewith transmitted.

2. This incomplete report is submitted now in order to make available the data already assembled and the conclusions drawn. Since further investigations are under way, it is probable that other data will be secured which will be added as an appendix.

HOMER HAMLIN,
Consulting Engineer

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REPORT ON GEOLOGICAL EXAMINATION OF IRON CANYON DAM AND RESERVOIR SITE.

The following report upon the Geological Examination of the Iron Canyon Dam and Reservoir site, on Sacramento River, Calif., is in response to a request from the chief of construction of the United States Reclamation Service, dated June 19, 1919.

During 1913 and 1914 the Iron Canyon project was investigated and reported upon by the United States Reclamation Service, in cooperation with the Iron Canyon Project Association. Extensive surveys and examinations were made during that investigation, including diamond drilling at the proposed dam site.

In 1914 the Secretary of the Interior appointed a board of review to consider the above-mentioned investigations and report.

The report of the cooperative investigation, accompanied by the report of the board of review, has been published under the title "Cooperative Investigations in California. Report on Iron Canyon Project by the Office of the United States Reclamation Service at Portland, Oreg., October, 1914, and Report by Board of Review Appointed by the Secretary of the Interior, November, 1914."

During the present year further investigations have been made by the United States Reclamation Service, the State of California, and the Iron Canyon Project Association, all working under a cooperative agreement. Part of this work has been additional diamond drilling at the proposed dam site, and at other localities.

PHYSIOGRAPHY.

Only the southern portion of the Iron Canyon region has been mapped on a large scale by the United States Geological Survey. The general topographic features of this section are shown on the accompanying map, Plate I. The area to the north of that shown on the map is very similar topographically. The region surrounding Iron Canyon was at one time a broad plain with a gentle southerly slope. Canyons and their tributaries have greatly dissected this plain, until at present it is a rough, hilly country, with but a few flat-topped hills and ridges—the remnants of the surface of the old plain.

Intermittent streams in the principal canyons west of Sacramento River flow in broad channels over sand and gravel bars. Blue Tent and Dibble canyons are examples. Downward erosion has nearly ceased in these canyons, but their tributaries are actively lowering their beds.

East of Sacramento River the gradients of the principal canyons are steeper than those on the west side, and their intermittent streams are rapidly lowering their channels. This contrast in topography is due to the greater relief on the east side of Iron Canyon, also to the prevalence of harder rocks there.

Iron Canyon is a rather mature gorge cut by Sacramento River, far below the surface of the old plain mentioned above. Downward erosion has progressed so far that all waterfalls and practically all rapids in the lower reaches of the canyon have been obliterated. From Big Bend to the mouth of Paynes Creek, a

distance of about 2 miles, Sacramento River flows in an inner gorge, very narrow and deep. Here the current is swift and turbulent. This portion of the river is known as Chinese Rapids. (See Pl. I.)

One striking feature of the region in and above Iron Canyon is the widely meandering course of Sacramento River, irrespective of the rock formations into which it has trenched its channel. The probable explanation is that at one time the stream flowed in a meandering channel over the old plain mentioned above, or a similar plain, and as the region was elevated the river maintained its old courses by downward cutting. It is a clear case of superimposed drainage.

GEOLOGY.

STRUCTURE.

The various formations in Iron Canyon have been but little disturbed by local folding—the principal structural feature being a flat anticline which crosses Sacramento River at section B–B. (Pl. V.) This anticline was not shown on the maps for the reason that it is believed to be somewhat local, and it was not traced out in detail. The crest of this fold trends approximately south 65° west and pitches between 2° and 3° in that direction. The dips on the northwest limb are about 7° to north 45° west, near the crest, but flatten much toward section A–A. The dips on the southeast limb are about 3°, but flatten rapidly toward the south.

No important faulting was noted in Iron Canyon.

FORMATIONS.

With the exception of the stream gravels, all of the formations in Iron Canyon are either volcanic rocks or sediments derived from such rocks. No general geological study was made of the surrounding region; but it is known that some of these formations, where exposed on the surface, cover many square miles. A description of the formations found in Iron Canyon follows, beginning with the oldest—that is, the lowest—stratigraphically.

LOWER SANDS.

The oldest formation seen in Iron Canyon has been designated the Lower Sands in this report. The areal outcrop of these beds is too small to be shown on Plate II, but a few feet in thickness of the upper portion can be seen in section B–B. Here the upper 2 feet of the formation consists of rather hard, yellowish, brown, and black sandstones derived from volcanic rocks. The log of hole C–1 indicates that the Lower Sands are at least 100 feet thick. The bottom of the formation was not reached, however.

The logs of holes C–1 and C–2 show that this formation is not all black sandstones, but that a bed of soft, yellowish, and brown tuff, some 20 feet thick, was struck about 10 feet below the top of the formation. It is, however, generally made up of slightly cemented sands derived from volcanic rocks.

The drill holes did not cave and C–1 yielded a light artesian flow of sulphurous water.

From what could be seen at the outcrop of the formation, and from an examination of the drill cores, it is apparent that the formation, on the whole, is quite pervious and not suitable for the foundation of a dam. The artesian flow encountered in hole C–1 and sulphurous springs in the vicinity corroborate this opinion.

AGGLOMERATE NO. 2.

At section B–B a bed of hard volcanic material, about 25 feet in thickness, rests upon the lower sands. In this report this bed will be designated as Agglomerate No. 2. The outcrop of the formation is small, as shown on Plates II and V. The anticlinal structure of the region soon carries it beneath the overlying formation both upstream and downstream. Sacramento River has excavated its channel entirely through this formation at section B–B and cut down into the Lower Sands to an unknown depth. Small rapids in Sacramento River downstream from section B–B show where Agglomerate No. 2 crosses the channel. It also crosses the channel upstream from section B–B, but no rapids mark this crossing.

Agglomerate No. 2 consists of volcanic ash, sand, pebbles, and blocks of lava. It is gray in color, hard and dense. It is not a sedimentary formation in the strict use of the term, as is shown by the subangular forms of the large aggregates. In other words, these aggregates do not exhibit the rounded forms resulting from wear due to long transportation by running water.

If this formation were located where topographic surroundings would permit the construction of a dam, and if it were thick enough and covered by an impervious formation, it would serve for the foundation of a dam. Unfortunately none of these conditions is met at this locality, the only place where it outcrops, in Iron Canyon.

UPPER SANDS.

A formation which in this report is designated by Upper Sands rests upon Agglomerate No. 2. The outcrops of this formation are much more extensive than those of Agglomerate No. 2 as shown on the map, Plate II. The Upper Sands rise above the level of Sacramento River at the mouth of Paynes Creek, are exposed for their full thickness at section B–B, and disappear below the river near the United States Geological Survey gaging station.

The lower portion of the Upper Sands, consisting of approximately 100 feet in thickness, of soft, black sandstones, with a subordinate fraction of volcanic tuffs, is very similar in general to the Lower Sands.

The black sands are exceedingly porous. When a 3-inch cube of dry sandstone is dipped into water for one second and then withdrawn, it ceases to drip water almost instantly. When held in water for three or four seconds it becomes entirely saturated. Obviousy these sands will transmit water very rapidly.

The upper portion of the Upper Sands consists of beds of black sand, yellow and brown sands, gravel. volcanic ash, and subangular blocks of lava. It appears to be in part a true volcanic agglomerate; but much of it has been worked over by water. It can be seen resting unconformably upon the lower portion of the Upper Sands on the left bank of Sacramento River near the easterly end of the Paynes Creek basalt flow, as shown on Plate II. It is but a few feet thick at this point. At section B–B it is much thicker, about 100 feet, and is a conspicuous feature as far downstream as the gaging station. The unconformity above noted indicates a cessation of the general subsidence of the region which had probably begun before the deposition of the Lower Sands. Then followed a period of elevation, during which part of the formations below were eroded and carried away. The upper portion of the Upper Sands was deposited on this eroded surface; hence both phases of this formation are of variable thickness.

Plate VII shows the Upper Sands as exposed on the left side of Iron Canyon a short distance downstream from section B–B. The lowest and apparently massive formation just above the river level is the lower portion of the Upper Sands, here finely laminated black sand. The stratified formation above is the

upper portion of the Upper Sands. The boulder-covered slope on the rim of the canyon is underlaid with Agglomerate No. 1, which will be described below.

No attempt was made to differentiate the two phases of this formation on the map, Plate II, showing the areal geology. To do so would have required much more field work than could be justified in this connection. In addition, no suitable topographic maps are available north of the area covered by Plate I. Such maps are essential in detailed geological work. It should be noted, however, that the two phases of the formation are differentiated on the sections where the necessary data are available. After field examinations and a study of the drilling records of the A, B, E, and F series of drill holes, it is the opinion of the writer that this formation is not suitable for the foundation or abutments of a dam.

AGGLOMERATE NO. 1.

The most important formation in Iron Canyon, so far as dam construction is concerned, is Agglomerate No. 1, the areal extent of which is shown on Plate II. This formation rests unconformably upon the Upper Sands.

This unconformity is an important feature, especially when considered in connection with the one which occurs within the Upper Sands. At the mouth of Paynes Creek, Agglomerate No. 1 can be seen in contact with the lower portion of the Upper Sands, the upper 100 feet or more of that formation having been removed by erosion. At section B–B, however, Agglomerate No. 1 rests directly upon the upper portion of the Upper Sands.

The top of the Upper Sands, due to erosion, is irregular, and the base of Agglomerate No. 1 follows all of these irregularities. For these reasons it is practically impossible to predict closely the position of the bottom of Agglomerate No. 1, its thickness, or the thickness of the Upper Sands, except near exposures of these formations. Such information can be developed only by drilling.

The surface exposures of this formation extend far beyond the limits of Iron Canyon toward the north and east, but it is covered with later deposits to the south and west. It is a typical volcanic agglomerate consisting of volcanic ash, mud, and sand, with subangular fragments and blocks of lava. One striking feature is the great number of large subangular blocks of lava embedded in the finer aggregates. Such blocks can be seen in the photographs of Plates VI and IX. The common arrangement of the aggregates in the formation is well shown in Plate VIII.

As noted above, the thickness of the formation is variable. Locally at section A–A it appears to be, at least, 150 feet thick as determined from the drill records and the topography. At section B–B it is now about 80 feet thick, but a portion has probably been removed by erosion. At section C–C it is from 110 to 120 feet thick as determined from the drill records and surface outcrops. Little is known regarding its thickness upstream from section A–A. Hole B–9, however, shows that it is at least 60 feet from the bottom of the wide gorge to the base of the formation. (See Plate III for the location of hole B–9.)

Field inspection and the drill records show that Agglomerate No. 1 is a dense and impervious formation suitable for a dam foundation and abutments. In general, this formation appears to be harder at section A–A than it is at section C–C, where drilling is now under way.

UPPER TUFF.

A thick series of volcanic tuffs, designated Upper Tuff in this report, rests upon Agglomerate No. 1 as shown on Plates II and V. This formation is now the surface rock over a great extent of country to the north, west, and south of the Agglomerate No. 1 area. Ample evidence can be seen, in the form of

numerous outliers of this formation, that it once covered all of Agglomerate No. 1 in the Iron Canyon region. Bald Hill, as shown on Plates I and II, is one of the outliers mentioned, and a similar one was noted on the opposite side of the canyon but beyond the limits of the map. It is conspicuous on both sides of the canyon in the vicinity of section C–C.

The Upper Tuff is an accumulation of fine volcanic material, ash, and sand, washed down from some region to the north or east, and deposited by running water. At the base it is markedly conglomeratic, containing thin but persistent beds of cemented pebbles and small boulders, in which basaltic material predominates. These basalt conglomerates can be seen at the river level near the westerly end of the proposed Bend embankment, on Bald Hill, and at other localities.

At the westerly end of the Bend embankment this series is at least 250 feet thick. Once it was probably thicker, for here it is capped by an extensive series of river gravels. This sudden change in the character of the formations probably indicates another unconformity and a period of surface erosion.

The Upper Tuff is a dense and impervious formation suitable for the foundation of the proposed Bend embankment.

OLD STREAM GRAVELS.

A thick series of river gravels and sands is found resting upon the upper tuff to the south and west of the proposed Bend embankment, the base of the formation being at about the 500-foot contour. These beds are of no special interest in this study, but show that some river, probably the Sacramento, once flowed over this area and laid down the gravel beds noted. The gravel deposits found in the beds of Blue Tent, Dibble, and other canyons in this region are derived from these older gravels.

HISTORY OF IRON CANYON.

After the deposition of the old stream gravels above mentioned the Iron Canyon region and the surrounding territory was elevated, probably very slowly and quite likely not uniformly. Coincident with this general elevation Sacramento River began to trench its course into the formation below; the erosion of Iron Canyon was initiated, and has continued to the present time.

Terrace deposits of hard, cemented, river gravel now at the 430-foot contour are evidence of a prolonged halt in the elevation of the region with a corresponding cessation in the deepening of the canyon, but downward cutting of Iron Canyon and its tributaries was subsequently continued until the bottom of the main gorge was trenched somewhat below the 300-foot contour at section A—A.

At this time in the history of the canyon a sheet of basaltic lava (Paynes Creek basalt) flowed down the old valley of Paynes Creek, completely filling it, and also filling Iron Canyon for a distance of at least a mile or two, and possibly much farther, to a depth of approximately 50 feet.

Sacramento River must have at once begun the cutting of a channel through the lava which obstructed its former channel. Falls at the downstream end of the lava flow must have soon developed, for the reason that the other formations in the canyon are much less resistant to erosion than basalt. The downstream end of the lava dam was undermined, falls were developed, and as the falls receded the stream cut a narrow steep-sided gorge through the basalt and deep into Agglomerate No. 1 and the Upper Sands. Since then erosion has removed all known traces of basalt from Iron Canyon and lowered the broad portion of the gorge some 40 feet or more, but the inner gorge, cut by the overflow from the now obliterated falls is still the low-water channel of Sacra-

mento River. This, in the opinion of the writer, is the manner in which the inner gorge was formed. It is difficult to imagine how any other agency could have excavated it. Very similar conditions have been noted by the writer on Verde River, Arizona, where the stream is now cutting an inner gorge through a lava sheet with soft formation below.

At the downstream end of the inner gorge the stream is deep and the current while swift is not turbulent, but upstream, about halfway to the Big Bend, the stream is much more rapid and turbulent. This portion of the inner gorge seems to be shallower, on the whole, than the lower portion.

Paynes Creek was displaced from its old valley by the basalt flow and has since cut a new canyon through the basalt and nearly through Agglomerate No. 1. It was proposed in the Cooperative Report to use this canyon as a portion of the spillway of the dam.

PAYNES CREEK BASALT.

As noted above, this lava sheet flowed down and completely filled the old valley of Paynes Creek, as shown on Plate II. This flow was not traced to its source or investigated beyond the limits of the map.

It exhibits all the features of a basalt flow, such as rude columnar structure in some places, surface pressure ridges, fissures, and scoriaceous zones, as shown in photographs Nos. 1 and 2. Its thickness at present varies from a few feet at the edges of the flow to 70 feet in the old valley of Paynes Creek, as shown by the records of Holes D–1, D–2, D–3, and D–4.

When the basalt flowed down Paynes Creek it buried the soil, sand, and gravel mantle which rested upon agglomerate No. 1. This old soil was penetrated in holes D–3 and D–4 where it is about 1 foot thick. These soil and gravel beds are conspicuous along the contact between the basalt and Agglomerate No. 1 on the left bank of Sacramento River, at section A—A, as shown in the photographs, Plates VI and VII, but are too thin to be shown on the sections.

Paynes Creek basalt is an exceedingly porous formation and in addition rests upon a thin bed of porous gravels and soil. Water will percolate through it very rapidly.

STREAM GRAVELS.

The most recent deposits in Iron Canyon are the stream gravels which partially fill the stream channel and form terraces along the banks in places. They are neither thick nor extensive, nor of especial importance in connection with this investigation; but may furnish material for constructon in case a dam is built.

DRILL RECORDS.

Below is the record of the drilling which has been done to test the formations at the three dam sites which have been considered. The writer has examined the cores from all the holes except the E and F series, and correlated the formations penetrated with the surface exposures of these rocks, where possible, as shown under the heading, "Description of formations," in the tables accompanying drill records. Some of the records have been condensed. The first elevation given is that of the ground surfaces at the point where the hole was drilled. The column headed "Thickness" corresponds with the driller's record and shows by summation, in some cases, the thickness of the various formations. The logs of the E and F series of drill holes were copied from the records of the United States Reclamation Service at Red Bluff, Calif., where all of the drill records may be examined if desired. The location of these drill holes is shown on the map, Plate III.

REVISED LOG OF HOLE A-1.

Elevation.	Thickness.	Description of formations.
258.0-242.0	16.0	Fine-grained, yellowish and brown tuff or sandstone, below Agglomerate No. 1.
242.0-237.5	4.5	Rather hard, fine-grained, laminated sandstone, dark gray to black in color and somewhat pebbly.
237.5-224.2	13.3	Fine grained, yellowish and brown tuff or sandstone occurring below Agglomerate No. 1.
224.2-223.2	1.0	Fine black sand carrying slight artesian flow.
223.2-208.5	14.7	Fine grained, brown to black sandstone or tuff, the same as that from 258. This bed yielded a slight artesian flow. The formation contains some grit and pebbles.
208.5-194.0	14.5	Soft, gritty, and pebbly fine sand, black or dark brown in color. This formation yields tepid sulphur water. From elevation 218.5-216 the formation is loose, but harder below. Artesian water rose 13.5 feet above the river level on completion of the well. Hole stood open without caving.

Total depth of hole A-1 is 64 feet.

REVISED LOG OF HOLE A-2.

Elevation.	Thickness.	Description of formations.
259.0-252.5	6.5	Agglomerate No. 1.
252.5-251.0	1.5	Water, bank undercut by the river.
251.0-236.2	14.8	Brown to black tuff or sandstone, containing a few pebbles. This is evidently the tuff and sand series below Agglomerate No. 1.
236.2-199.0	37.2	Black to dark brown, pebbly tuff or sandstone, same as from elevation 251 to 236.2
199.0-185.5	13.5	Soft, gritty, and pebbly sand, fine, and black to dark brown in color. At elevation 199 a flow of sulphur water was struck.

Total depth of hole A-2 is 73.5 feet.

REVISED LOG OF HOLE A-3.

Elevation.	Thickness.	Description of formations.
259.5-253.5	6.0	Agglomerate No. 1.
253.5-245.5	8.0	Fine-grained, yellowish to brown tuff, with hard streaks.
245.5-241.5	4.0	Fine-grained, yellowish to brown tuff, containing a few pebbles.
241.5-232.5	9.0	Black sand or sandy tuff.
232.5-220.5	12.0	Fine-grained, yellowish to brown tuff the same as from 241.5 to 253.5.
220.5-206.5	14.0	Coarse black sand, rather soft. This is also part of the tuff series below Agglomerate No. 1.
206.5-194.5	12.0	Coarse sandy formation, slightly cemented. There is an artesian flow from this horizon.
194.5-188.5	6.0	Black sand or sandy tuff, loose on top, cemented toward the bottom.

Total depth of hole A-3 is 71 feet.

REVISED LOG OF HOLE A-4.

Elevation.	Thickness.	Description of formations.
261.2-253.2	8.0	Agglomerate No. 1.
253.2-247.2	6.0	Black sand containing pebbles of igneous rocks.
247.2-239.2	8.0	Fine-grained, yellowish to brown tuff.
239.2-225.2	14.0	Do.
225.2-222.2	3.0	Coarse, black sand or pebbly tuff.
222.2-209.2	13.0	Dark, sandy tuff
209.2-201.2	8.0	Coarse, black sand.
201.2-192.2	9.0	Soft, black sand. Hole caved as it was drilled.

A slight artesian flow was struck at elevation 231.2.
Total depth of hole A-4 is 69 feet.

REVISED LOG OF HOLE A-5.

Elevation.	Thickness.	Description of formations.
261.0-256.0	5.0	Agglomerate No. 1.
256.0-249.5	6.5	Black sand containing pebbles of igneous rocks.
249.5-223.0	26.5	Yellowish, brown, and black sandy tuff.
223.0-222.0	1.0	Black sand.
222.0-205.0	17.0	Black sand. This bed is soft at elevation 205 to 207.

Slight artesian flow was struck at elevation 205.
Total depth of hole A-5 is 56 feet.

REVISED LOG OF HOLE B-1.

Elevation.	Thickness.	Description of formations.
258.6–236.1	22.5	Agglomerate No. 1.
236.1–226.6	9.5	Do.
226.6–217.6	9.0	Fine, black sand and pebbles.

There is considerable doubt as to the base of Agglomerate No. 1. Hole caves at bottom.
Total depth of hole B-1 is 41 feet.

REVISED LOG OF HOLE B-2.

Elevation.	Thickness.	Description of formations.
258.6–242.6	16.0	Agglomerate No. 1.
242.6–224.6	18.0	Sand seam (river sand?). Possibly an undercut bank.
224.6–219.6	5.0	Agglomerate No. 1.
219.6–217.6	2.0	Coarse, black sand (possibly river sand?).
217.6–210.6	7.0	Yellowish and gray, fine-grained, clay-like tuff.
210.6–209.6	1.0	Material not given in driller's notes (black sand?).

Total depth of hole B-2 is 49 feet.

REVISED LOG OF HOLE B-3.

Elevation.	Thickness.	Description of formations.
263.0–204.0	59.0	Agglomerate No. 1.
204.0–201.0	3.0	Hard, black sand. Struck an artesian flow of about 20 gallons per minute in this formation.
201.0–183.0	18.0	Hard, fine-grained, black sand or sandy tuff. It may be possible that the tuff beds below Agglomerate No. 1 contain hard beds from 1 to 2 feet thick.
183.0–163.0	20.0	Fine, slightly cemented, black sand. Loose sand struck at elevation 163 which caves. Artesian pressure of well when completed was 16 feet above the surface.

Total depth of hole B-3 is 100 feet.

REVISED LOG OF HOLE B-4.

Elevation.	Thickness.	Description of formations.
259.8–246.8	13.0	Agglomerate No. 1.
246.8–237.8	9.0	Do.

This well did not penetrate to the bottom of Agglomerate No. 1.
Total depth of hole B-4 is 22 feet.

REVISED LOG OF HOLE B-5.

Elevation.	Thickness.	Description of formations.
267.3–238.8	28.5	Agglomerate No. 1.
238.8–232.3	6.5	Slightly cemented, black sand.
232.3–225.3	7.0	Black sand according to the core saved. The driller's notes state that the formation is very soft tuff.
225.3–218.3	7.0	Do.
218.3–212.3	6.0	Soft, claylike tuff.
212.3–207.3	5.0	Fine, claylike tuff, somewhat sandy.
207.3–198.3	9.0	Black sand according to the core saved. The driller's notes state that the formation is sand with streaks of claylike material.
198.3–187.3	11.0	Same as above.
187.3–180.3	7.0	Sand and coarse gravel which caves badly. No sample at this horizon.

A slight artesian flow was struck at elevation 199.3.
This hole is on the axis of the proposed dam.
Total depth of hole B-5 is 87 feet.

REVISED LOG OF HOLE B–6.

Elevation.	Thickness.	Description of formations.
260.7–216.7	44.0	Agglomerate No. 1.
216.7–209.7	7.0	Yellowish and brown tuff containing pebbles up to one-half inch in size.
209.7–207.7	2.0	Loose sand. Caves badly. May be river sand.
207.7–205.7	2.0	Lava rock, probably a boulder.
205.7–172.7	33.0	Black sand or very sandy tuff with streaks of claylike material.
172.7–170.7	2.0	Sample shows only pebbles. Formation is probably pebbly black sand.
170.7–140.7	30.0	Probably soft black sand. No sample saved.

Slight artesian flow at elevation 196.7.
Artesian pressure on the completion of the well was 15 above the surface.
Total depth of hole B–6 is 120 feet.

REVISED LOG OF HOLE B–7.

Elevation.	Thickness.	Description of formations.
259.9–221.9	38.0	Water. Well is located in Sacramento River.
221.9–218.9	3.0	Coarse gray sand (river sand?).
218.9–212.9	6.0	Same as above.
212.9–204.9	8.0	Soft yellow and brown tuff as shown by core sample. The driller's notes state that the formation is "finely cemented sand or slightly cemented tuff."
204.9–199.9	5.0	Soft yellow and brown tuff.

Slight artesian flow at elevation 199.9.
Total depth of hole B–7 is 60 feet.

REVISED LOG OF HOLE B-8.

Elevation.	Thickness.	Description of formations.
288.7–282.2	6.5	Agglomerate No. 1.
282.2–278.7	3.5	Do.
278.7–271.7	7.0	Fine black sand. Hole does not cave.
271.7–253.2	18.5	Same as above, but with streaks of fine sand and gravel.

Total depth of hole B–8 is 35.5 feet.

REVISED LOG OF HOLE B–9.

Elevation.	Thickness.	Description of formations.
273.8–266.8	7.0	Agglomerate No. 1.
266.8–255.8	11.0	Sand with gravel from one-fourth to one-half inch in size.
255.8–253.8	2.0	Streaks of sand with clay.
253.8–244.8	9.0	Soft tuff with a few small boulders. It seems like Agglomerate No. 1, but am uncertain. It may be a misplaced core sample.
244.8–229.8	15.0	Soft yellow tuff containing pebbles.
229.8–213.8	16.0	Agglomerate with hard boulders. It seems like Agglomerate No. 1, but am not certain. It also may be a misplaced core.
213.8–208.3	5.5	Slightly cemented black sand.

Hole does not cave and is water-tight.
Total depth of hole B–9 is 65.5 feet.

REVISED LOG OF SHAFT

Elevation.	Thickness.	Description of formations.
268.0–227.0	41.0	Agglomerate No. 1.
227.0–226.0	1.0	Loose water bearing sand.
226.0–216.4	9.6	Gravel and sand with an increasing amount of water.

Upon the completion of the shaft water rose to a level 1½ feet above the water level in the river.
Total depth of the shaft is 51.6 feet.

REVISED LOG OF HOLE C-1.

Elevation.	Thickness.	Description of formations.
257.6–247.1	10.5	River sand and boulders.
247.1–241.6	5.5	Yellowish and brown sandy tuff—very soft with gritty streaks.
241.6–226.6	15.0	Same as above.
226.6–220.6	6.0	Hard, brown sandstone.
220.6–214.6	6.0	Hard, black and brown sandstone.
214.6–156.6	58.0	Slightly cemented, black sand—finer near the bottom.

Light artesian flow at elevation 217.6 increasing in volume to elevation 167.5 when total discharge was 24 gallons per minute. Water is sulphurous.
Hole does not cave.
Total depth of hole C-1 is 101 feet.

REVISED LOG OF HOLE C-2.

Elevation.	Thickness.	Description of formations.
258.7–242.7	16.0	Agglomerate containing subangular blocks of felsite lava. Some of these lava blocks are 2 to 3 feet in size and from that size range down to pebbles. This formation is exposed on the right bank of the river and has been designated Agglomerate No. 2 in these notes.
242.7–230.7	12.0	Same as above according to the core sample. The driller's notes state that this formation is fine-grained tuff resembling sandstone.
230.7–183.7	47.0	Slightly cemented, black sand, with streaks of very soft sand.

Hole does not cave.
Total depth of hole C-2 is 75 feet.

REVISED LOG OF HOLE D-1.

Elevation.	Thickness.	Description of formations.
365.4–344.4	21.0	Basalt, much broken. This is the Paynes Creek lava flow.
344.4–342.4	2.0	Cavity in lava, filled with earth.
342.4–337.4	5.0	Basalt, Paynes Creek lava flow.
337.4–327.9	9.5	Cavity in lava, filled with earth.
327.9–294.4	33.5	Basalt, much broken and full of crevices and cavities. Still Paynes Creek lava flow.
294.4–252.9	41.5	Agglomerate No. 1.
252.9–249.4	3.5	Sand.
249.4–233.4	16.0	Seams of tuff and conglomerate.

Total depth of hole D-1 is 132 feet.

REVISED LOG OF HOLE D-2.

Elevation.	Thickness.	Description of formations.
362.3–314.3	48.0	Basalt, much broken and with many cavities and crevices. This is the Paynes Creek lava flow.
314.3–307.3	7.0	Agglomerate No 1.

Total depth of hole D-2 is 55 feet.

REVISED LOG OF HOLE D-3.

Elevation.	Thickness.	Description of formations.
374.1 –371.1	3.0	Soil and boulders.
371.1 –365.1	6.0	Coarse-grained basalt. At elevation 367.1 struck small crevice and lost water. At elevation 365.1 struck another seam and lost water. Cemented and the hole remained tight.
365.1 –315.85	49.25	Hard, fine-grained basalt. Hole remained water-tight to elevation 315.85. Got 100 per cent core. This formation is the Paynes Creek lava flow.
315.85–314.5	1.35	Dirt and gravel, lost water.
314.5 –303.9	10.6	Agglomerate No. 1.

Total depth of hole D-3 is 70.2 feet.

REVISED LOG OF HOLE D-4.

Elevation.	Thickness.	Description of formations.
363.3–333.8	29.5	Porous and broken basalt. This formation is the Paynes Creek lava flow.
333.8–332.8	1.0	Earth and gravel.
332.8–331.3	1.5	Agglomerate No. 1.

Hole caved badly from elevation 333.8 to 332.8.
Total depth of hole D–4 is 32 feet.

REVISED LOG OF HOLE D-5.

Elevation.	Thickness.	Description of formations.
298.3–294.8	3.5	Agglomerate No. 1 (?).
294.8–292.8	2.0	Loose gravel (river gravel?).
292.8–228.3	64.5	Agglomerate No. 1 (?). This formation breaks up badly and does not core, but is water-tight.

Total depth of hole D–5 is 70 feet.

REVISED LOG OF HOLE D-6.

Elevation.	Thickness.	Description of formations.
264.2–252.2	12.0	Hard conglomerate. Agglomerate No. 1.
252.2–250.2	2.0	Soft conglomerate. Agglomerate No. 1.
250.2–245.7	4.5	Hard conglomerate. Agglomerate No. 1.
245.7–231.7	14.0	Soft conglomerate. Agglomerate No. 1.
231.7–224.2	7.5	Tuff.
224.2–202.2	22.0	Sand, partly indurated, or sandy tuff, containing artesian water.
202.2–201.2	1.0	Light-gray tuff.
201.2–184.2	17.0	Sandy tuff.
184.2–150.7	33.5	Sand varying in hardness, partly indurated.
150.7–148.2	2.5	Tuff with interbedded lava boulders.
148.2–121.2	27 0	Soft, gray tuff.
121.2–119.2	2.0	Sand with a flow of artesian water.
119.2– 95.7	23.5	Tuff, or tuff conglomerate.
95.7– 92.2	3.5	Hard, black lava (boulder).
92.2– 84.2	8.0	Tuff.
84.2– 79.2	5.0	Sand and gravel.
79.2– 74.2	5.0	Tuff.
74.2– 59.2	15.0	Sand.

Hole stands open below elevation 151.2. Upon the completion of the well the artesian flow was 75 gallons per minute. The artesian head was 32 feet above the river level.
Artesian water was struck at elevations 224.2, 201.2, 150.7, 121.2, 119.2, and probably at 59.2.
Total depth of hole D–6 is 205 feet.

REVISED LOG OF HOLE D-7.

This well was located, but drilling has been delayed.

REVISED LOG OF HOLE D-8.

This well was located, but drilling has been delayed.

REVISED LOG OF HOLE D-9.

Elevation.	Thickness.	Description of formations.
258.0–211.0	47.0	Water. Well located in the Sacramento River.
211.0–209.5	1.5	Sand and gravel.
209.5–192.7	16.8	Hard dark rock, supposed to be andesite, boulder.
192.7–189.0	3.7	Agglomerate No. 1.
189.0–185.0	4.0	Andesite, boulder.
185.0–184.5	.5	Agglomerate No. 1.
184.5–181.2	3.3	Andesite, boulder.
181.2–175.7	5.5	Agglomerate No. 1.

Some of the andesite was very hard and made good core; but there was a lot of soft decomposed andesite which did not core. No sand or gravel seams were found in this hole, and it was water-tight all the way.
This well is located in Sacramento River 1,550 feet upstream from the Hopson dam-site axis.
Total depth of hole D-9 is 82.3 feet.

REVISED LOG OF HOLE E-1.

Elevation.	Thickness.	Description of formations.
257.0–246.0	11.0	Agglomerate No. 1. Does not make good core.
246.0–240.7	5.3	Agglomerate No. 1. Harder than above.
240.7–237.0	3.7	Tuff. Small flow of artesian water at elevation 240.
237.0–232.3	4.7	Caving sand.
232.3–219.0	13.3	Tuff.
219.0–209.5	9.5	Tuff—getting softer—makes about 40 per cent core.
209.5–209.0	.5	Coarse, black sand.
209.0–204.0	4.0	Fine, packed sand with seams of tuff.
204.0–197.0	7.0	Black, sandy tuff with seams of dark blue clay.
197.0–187.0	10.0	Fine, loose sand, drill rods wash down when released. Cores of soft clay and sand recovered.
187.0–179.0	8.0	Coarse gravel—size of peas.

Casing was put down to elevation 180, but could not be driven deeper on account of coarse sand binding at elevation 232.

Water forced into the hole gets away freely at elevations 197 and 179 and does not return, making it impossible to go deeper with this rig without cutting off the sand at elevation 232 with larger casing.

Fine packed sand at elevation 209 to 204 will not core when drilling under ordinary conditions with water, but samples can be obtained by drilling dry. The core obtained in this way is soft and can be crumbled between the thumb and finger. It would wash away under water pressure. Loose sand, fine at elevation 197 increasing in coarseness to elevation 179 where it is gravel size of peas and larger.

Surface elevation of this hole is equal to 5 on United States Geological Survey gage.

Small flow of sulphur water stood at about 10 feet above low water in the river on the completion of the well.

Total depth of hole E–1 is 78 feet.

REVISED LOG OF HOLE E-2.

Elevation.	Thickness.	Description of formations.
255.0–221.0	34.0	Agglomerate No. 1, soft, no core, except embedded rocks.
221.0–214.5	4.5	Fine, packed sand, no core.
214.5–210.0	6.5	Tuff and conglomerate in alternating beds.
210.0–200.0	10.0	Tuff.
200.0–197.0	3.0	Tuff and conglomerate in alternating beds.

Hole holds water. No caving. No artesian flow.

Total depth of hole E–2 is 58 feet.

LOG OF HOLE E-3.

Elevation.	Thickness.	Description of formations.
253.0–246.5	6.5	Water, Sacramento River.
246.5–245.0	1.5	Sand.
245.0–244.0	1.0	Hard conglomerate.
244.0–240.0	4.0	Soft, red agglomerate—coarse like sandstone; rods could be twisted down by hand through this.
240.0–234.0	6.0	Harder agglomerate, hole caving, red sand.
234.0–232.0	2.0	Soft red agglomerate. Rods twisted down by hand. Red sandstone, caving.
232.0–228.0	4.0	Harder agglomerate. Hole caving badly. Had to ream hole for casing. Put down casing to 25 feet.
228.0–173.0	55.0	Agglomerate, soft; no core except of embedded blocks of lava.
173.0–155.0	18.0	Agglomerate, harder; 25 to 30 per cent core obtained.
155.0–142.5	12.5	Tuff, 50 per cent core.

At elevation 152 small stream of artesian, sulphur water, which increased between elevations 152 and 143 to about 12 gallons per minute. No sand seams and no caving below a depth of 25 feet; that is, elevation 223.

The following note was added by Mr. H. J. Gault: "It will be noted that the agglomerate at this hole, E–3 is softer than at any other hole drilled so far in Iron Canyon, some parts being loose sand caving in the hole and necessitating the use of casing. Down to 80 feet no core was obtained except of the embedded rocks, which are few and small, not over 6 inches through. About 10 to 15 per cent of core was obtained from these rocks, which are blocks of lava. It is also noted that the agglomerate here runs much deeper than was expected from the indications at E–1 and E–2. Between these two holes the dip of the bottom of the agglomerate is 20 feet in 1,300 feet downstream, and to conform with that dip it should be found at 42 feet below the water surface at E–2, instead of 98 feet as actually found."

Total depth of hole E–3 is 110.5 feet.

Hole E–3 is located in the middle of Sacramento River, 2,100 feet downstream from the United States Geological Survey gaging station.

LOG OF HOLE E-4.

Elevation.	Thickness.	Description of formations.
253.0-247.0	6.0	Water, Sacramento River.
247.0-178.0	69.0	Agglomerate, soft, no core except from lava boulders; about 20 per cent core, practically all from bowlders.
178.0-176.0	2.0	Caving, red sand.
176.0-126.0	50.0	Agglomerate, soft, no core except from boulders.

Total depth of hole E-4 is 127 feet.
Hole E-4 is located in the middle of Sacramento River 2,800 feet downstream from the United States Geological Survey gaging station.

REVISED LOG OF HOLE F-1.

Elevation.	Thickness.	Description of formations.
262.0-259.5	2.5	Sandy tuff alternating with coarse sandy seams.
259.5-254.5	5.0	Loose sand and coarse gravel.
254.5-252.0	2.5	Very coarse gravel.
252.0-242.0	10.0	Sand with some seams of gravel; water does not return.
242.0-238.0	4.0	Fine, black sand.
238.0-234.5	3.5	Tuff.
234.5-206.5	28.0	Agglomerate No. 2 (?). This agglomerate is fairly soft, will not make a core, and is harder toward the bottom.
206.5-205.5	1.0	Very coarse gravel; water does not return. Could not go deeper without reaming hole to take larger casing.

Well F-1 is 6,100 feet upstream from the United States Geological Survey gaging station and 1,600 feet downstream from well C-2.
Total depth of hole F-1 is 57 feet.

REVISED LOG OF HOLE F-2.

Elevation.	Thickness.	Description of formations.
257.0-254.0	3.0	Sandy tuff; stands up, but does not core.
254.0-253.5	.5	Harder tuff, makes core.
253.5-251.0	2.5	Sand, caving slightly.
251.0-242.5	8.5	Agglomerate No. 2 (?).
242.5-240.5	2.0	Sandy tuff; got core by drilling dry.
240.5-235.0	5.5	Coarse gravel and sand, caves badly.
235.0-230.5	4.5	Fine sand, caving.
230.5-229.0	1.5	Black sand, partly indurated. Hole stands partly open.

Total depth of hole F-2 is 28 feet.

DAM SITES.

DAM SITE NEAR SECTION A-A.

The dam site proposed and recommended in the Cooperative Report is located near section A-A, as shown on Plate II.

The one favorable feature of this site is the considerable thickness, about 35 feet, of Agglomerate No. 1 over the entire base of the proposed dam, except for the narrow inner gorge, shown on section A-A and described above. At section A-A Agglomerate No. 1 is a rather hard, dense, and impervious formation which, if other less favorable conditions could be met, would serve as an excellent foundation for an earth, a rock-fill, or a masonry dam.

The unfavorable conditions at this dam site are:

(1) Agglomerate No. 1 and the Upper Sands dip upstream, an attitude which favors a percolation outward from beneath Agglomerate No. 1.

(2) The Upper Sands, beneath Agglomerate No. 1, are pervious, as shown by the fact that nearly all drill holes of the A and B series yielded artesian

water, which in some holes would rise 15 feet or more above the level of the river. Special attention is directed to the record of hole D–6, which now yields an artesian flow of 75 gallons per minute, and the water will rise about 30 feet above the level of the river.

(3) At the proposed dam site Sacramento River has cut an inner gorge entirely through Agglomerate No. 1 and into the Upper Sands below. How far upstream this condition extends is unknown, since no drill records are available in that direction, except hole B–9. In that hole the Upper Sands were struck at elevation 214. At section A–A they were struck at elevation 225. It is entirely possible that Agglomerate No. 1 has been cut through as far upstream as hole B–9. In any event a long stretch of the Upper Sands is uncovered in the bottom of the inner gorge, where leakage will occur if not covered with an impervious fill. The placing of this fill will be an expensive and uncertain task.

(4) Paynes Creek basalt is a very pervious formation and is underlaid by a thin bed of porous stream gravel. In its present condition it will, in the opinion of the writer, leak to a prohibitive degree. To make it water-tight, a cut-off wall must be built, extending well down into Agglomerate No. 1, along the axis of the proposed spillway. This will be an expensive operation, as the wall must go down some 80 feet at hole D–1. In addition a spillway structure must be built on the surface of the basalt for a distance of approximately one-half mile. In places this dam will be 25 feet or more in height.

(5) It is the opinion of the writer that extensive erosion will occur in Paynes Creek Canyon if the spillway of the proposed dam is built as located. This canyon is from 50 to 75 feet deep, but 300 feet wide at the top in the most constricted portion, and has a very steep gradient. Agglomerate No. 1 has already been so extensively trenched by this stream that but 33 feet of the basal beds remain above the upper sands at hole D–6, and much less at hole B–8 if the drill record is correct.

Obviously little if any of the water which would flow over the proposed spillway could cross Paynes Creek Canyon. The result would be concentrated flow in the canyon, rapid erosion, and deepening of the present channel. After Agglomerate No. 1 had been scoured away, the overflow would cut deep into the remaining 100 feet of the Upper Sands. In addition, water flowing over the west wall of the canyon would certainly erode Agglomerate No. 1 and undermine the basalt above. The conditions would be very similar to those which preceded the cutting of the inner gorge.

When all the adverse conditions at this site have been considered it is not believed by the writer that a dam such as proposed or any other type of dam is practicable at this site.

DAM SITE NEAR SECTION B–B.

Prof. A. C. Lawson, of the University of California, in a report to Mr. W. F. McClure, State Engineer of California, dated August 21, 1919, suggested an investigation at a possible dam site a short distance downstream from section B–B. The location of section B–B is shown on Plate II. A copy of Prof Lawson's report forms Appendix No. 3 of this report.

In that report he states: "I therefore recommend that engineering investigations be directed to this site and a series of borings be put down, none of which needs to exceed 100 feet below low water, to test the conclusions based upon a geological examination of the surface."

Hole F–1 was accordingly put down at a point about 1,600 feet downstream from hole C–2, the results of which are shown in the drill records herewith.

At C–1 the top of Agglomerate No. 2, here 25 feet thick, is at elevation 290, as determined by aneroid. In hole F–1 Agglomerate No. 2, here 28 feet thick, was struck at elevation 234, indicating an average dip of about 1¾° downstream instead of 2° to 3°, as indicated by surface observations. Agglomerate No. 2, here but 9 feet thick, was struck in hole F–2 at elevation 251.

If surface dips alone were considered, it might appear that Agglomerate No. 2 had not been struck in hole F–1 or hole F–2, but an inspection of the walls of the canyon did not reveal any other formation which might be mistaken for it underground. The surface dips also flatten very markedly to the south of section B–B, according to the observations of the writer.

The Upper Sands, which rest upon Agglomerate No. 2 at the dam site proposed by Prof. Lawson, is the same formation which rises from beneath Agglomerate No. 1 at the dam site near section A–A. At this lower site the Upper Sands, with a few intercalated beds of tuff and gravel strata, are about 100 feet thick. This formation is admittedly pervious at section A–A, and there is no reason to suppose that it is less pervious here. Mere elevation above Sacramento River and the hydrostatic head of the artesian water found in this region do not signify water-tightness.

In the opinion of the writer this formation is not tight enough to serve for the abutments of a dam here or at any other locality where it is exposed. Here Agglomerate No. 2 is not thick enough to serve as the foundation for an overflow type of masonry dam. The thickness as shown by surface outcrops and borings is only from 9 to 28 feet. Topographic surroundings do not permit the construction of adequate spillways at either or both ends of the proposed dam, since it is located in a deep gorge. Adequate spillway capacity is absolutely essential.

In the opinion of the writer this site is not suitable or safe for a masonry dam, and any other type seems fully as impracticable.

DAM SITE NEAR SECTION C–C.

Investigations are now being made, at the suggestion of the writer, at and below cross section C–C. It was thought that surface indications justified the drilling of a series of test holes here for the following reasons:

(1) The formations dip down stream.

(2) The probability of Agglomerate No. 1 being thick enough to serve as the foundation of a dam.

(3) Topographic conditions which will permit the construction of a long spillway.

A topographic map of this locality is being prepared and four holes have been sunk, E–1 to E–4. Sufficient data have not yet been secured on which to base a final conclusion; but the indications to date are not as favorable as could be wished. Agglomerate No. 1 is apparently much softer than at other localities in Iron Canyon. More extended tests will be made.

IRON CANYON RESERVOIR SITE.

A trip was made through the reservoir site and nothing was seen which would indicate that it will not be satisfactory. The two formations most conspicuous are Agglomerate No. 1 and the Upper Tuff, the general relation of which is shown on section D–D. Toward the upper end of the proposed reservoir extensive beds of gravel appear, but they are underlaid by impervious beds and need give no concern regarding leakage.

LOS ANGELES, CALIF., *December 12, 1919.*

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Contour interval 10 feet.

Datum is mean sea level.

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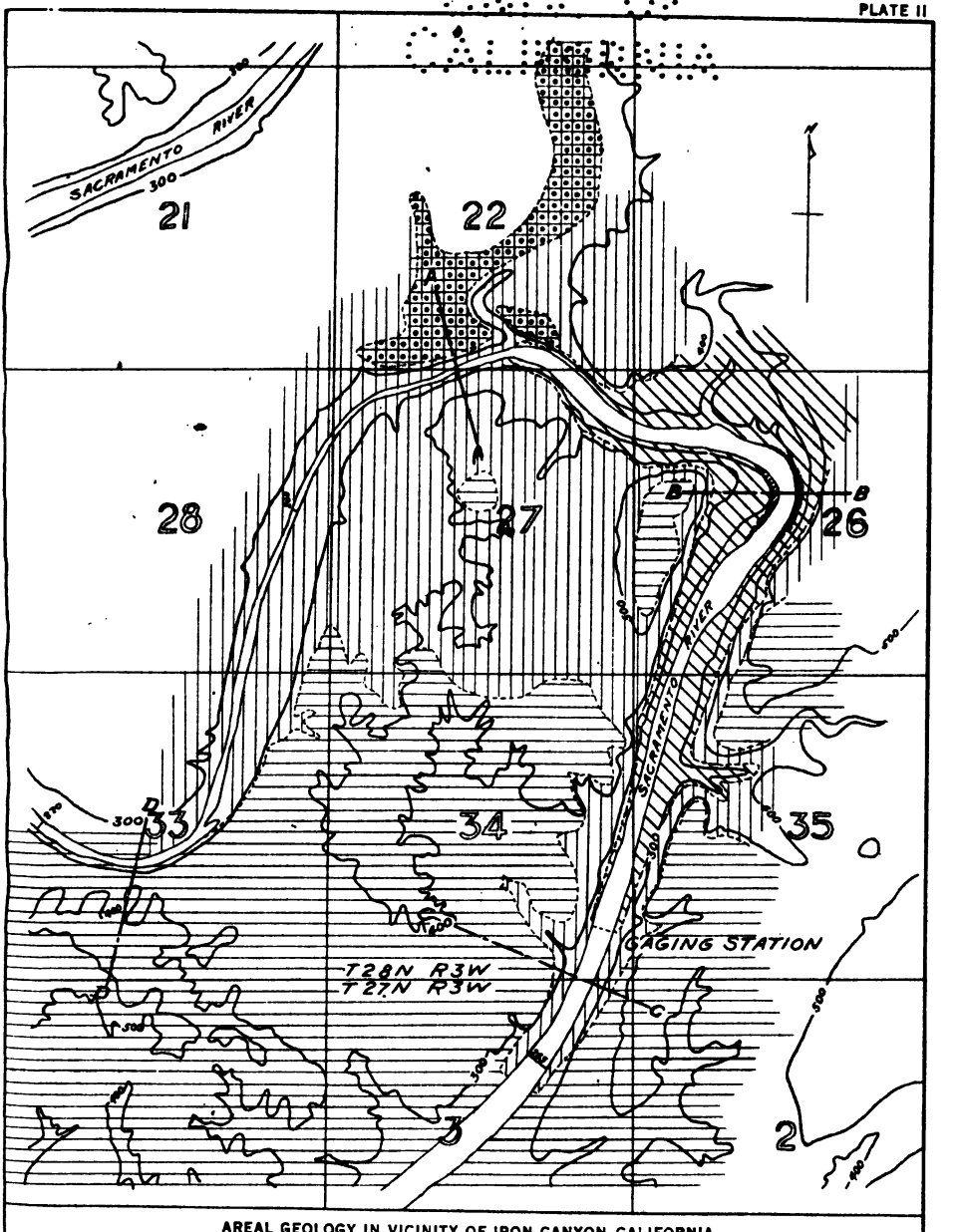

AREAL GEOLOGY IN VICINITY OF IRON CANYON, CALIFORNIA.

PAYNES CREEK BASALT

AGGLOMERATE NO. 1

UPPER TUFF

UPPER SANDS

ONE MILE

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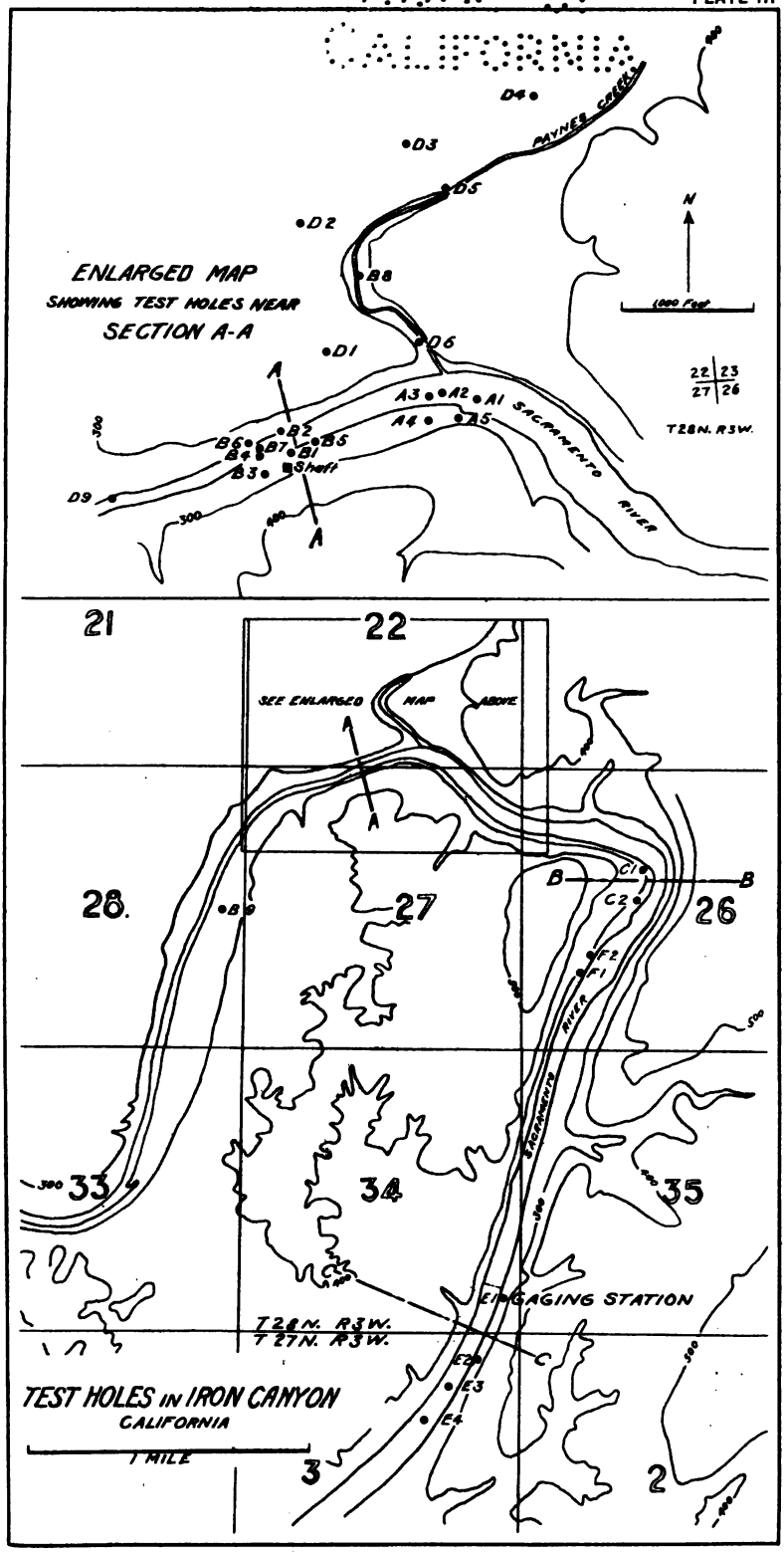
ENLARGED MAP
SHOWING TEST HOLES NEAR
SECTION A-A
D4
D3
D5
D2
B8
D1
D6
A3
A2
A1
A4
A5
B6
B7
B5
B4
B1
B2
B3
Shaft
D9
A
PAYNES CREEK
SACRAMENTO RIVER
N
1000 Feet
22 | 23
27 | 26
T28N. R3W.
21
22
SEE ENLARGED MAP ABOVE
28
B9
27
26
B
C1
C2
F2
F1
33
34
35
E1
GAGING STATION
T26N. R3W.
T27N. R3W.
C
E2
E3
E4
TEST HOLES IN IRON CANYON
CALIFORNIA
1 MILE
3
2

UNIV. OF
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PLATE IV

PLATE IV

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CALIFORNIA

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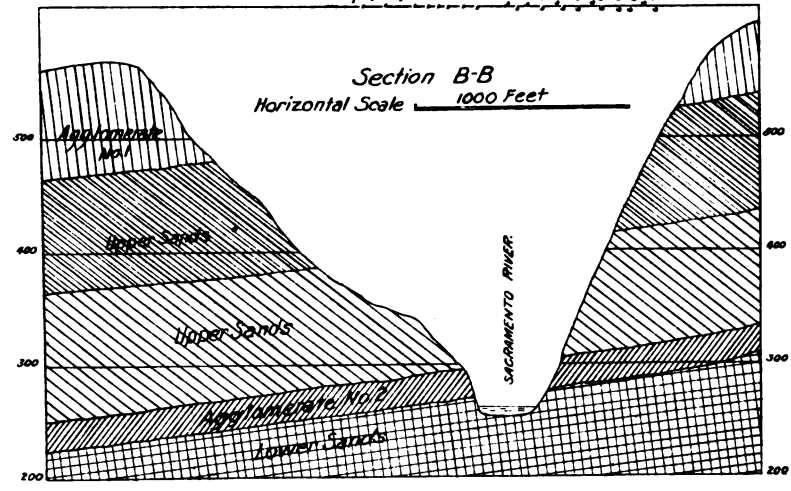
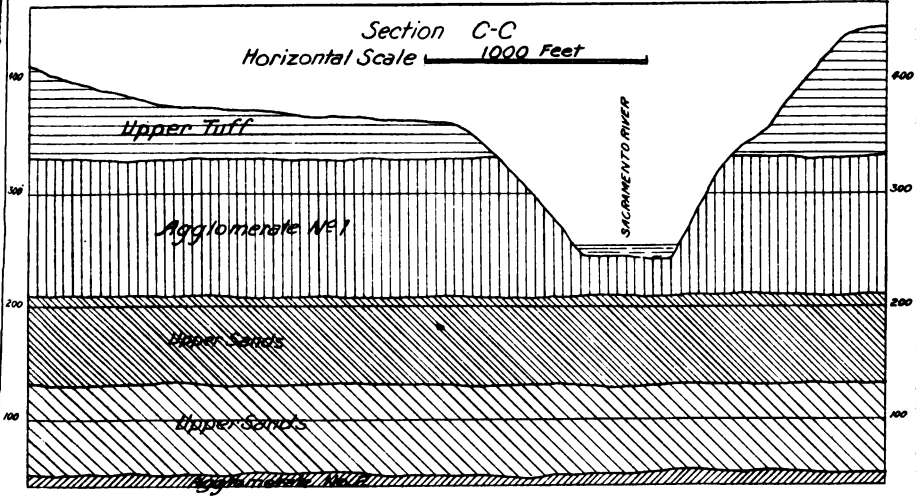
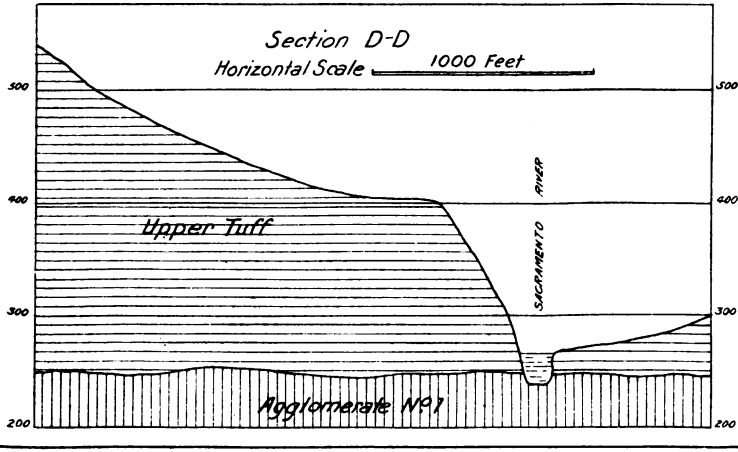

Section B-B
Horizontal Scale 1000 Feet
500
400
300
200
Agglomerate No.1
Upper Sands
Upper Sands
SACRAMENTO RIVER
Agglomerate No.2
Lower Sands


Section C-C
Horizontal Scale 1000 Feet
400
300
200
100
Upper Tuff
SACRAMENTO RIVER
Agglomerate No.1
Upper Sands
Upper Sands


Section D-D
Horizontal Scale 1000 Feet
500
400
300
200
SACRAMENTO RIVER
Upper Tuff
Agglomerate No.1

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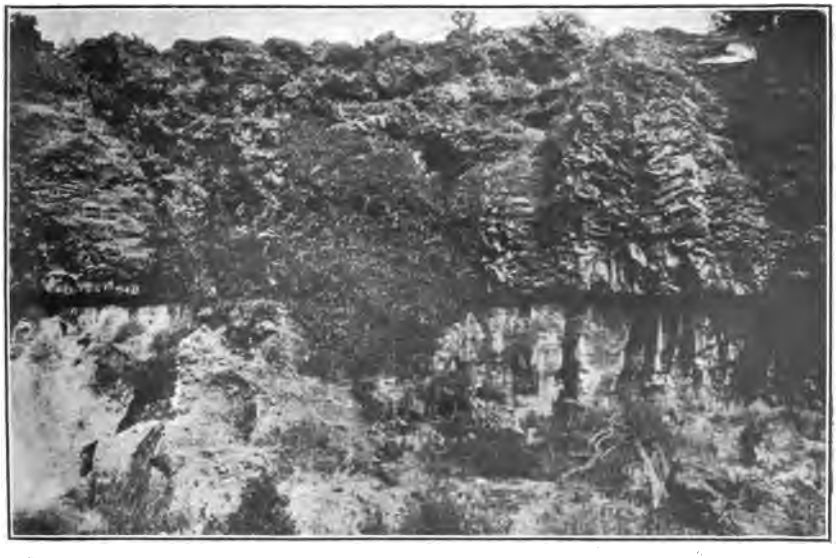
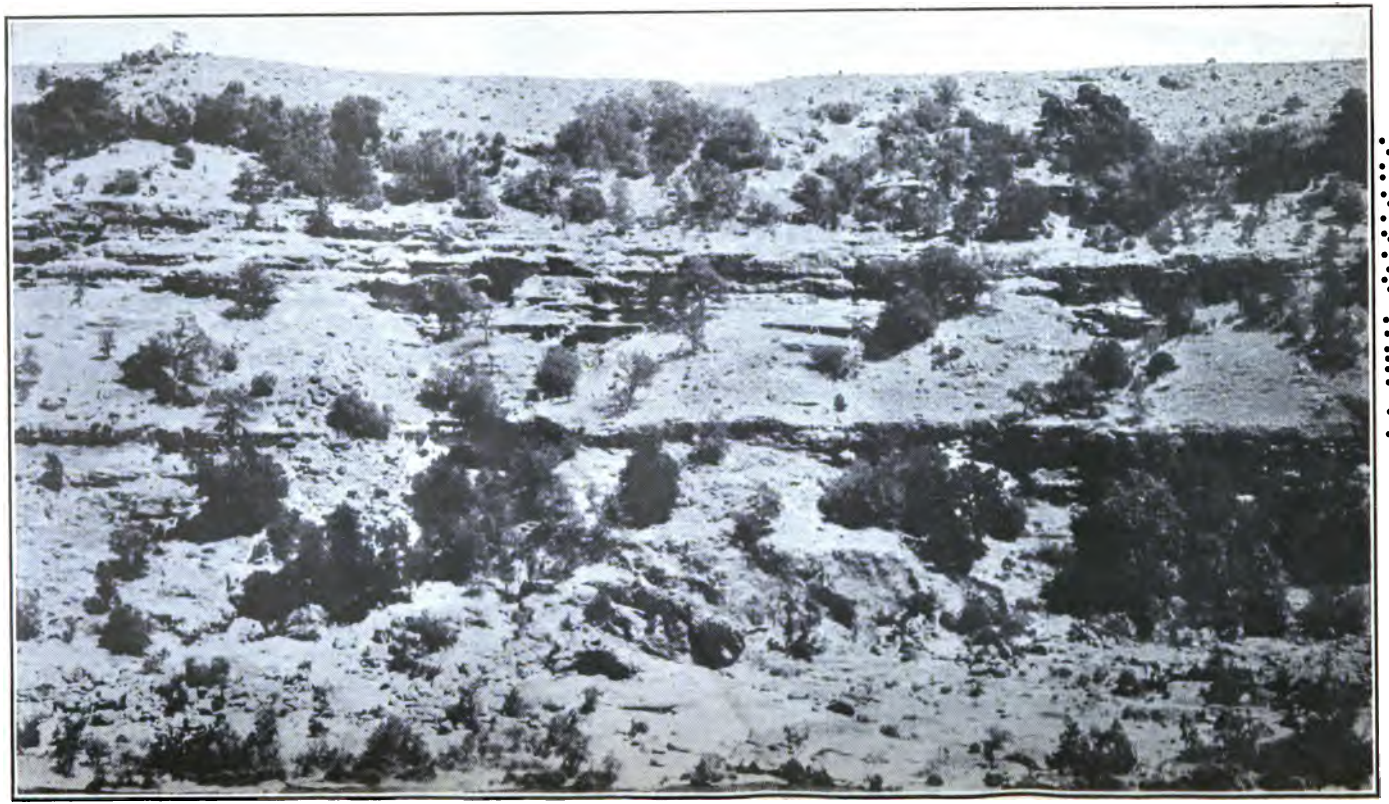
A. PAYNES CREEK BASALT RESTING UPON AGGLOMERATE NO I, LEFT BANK OF SACRAMENTO RIVER, AT WESTERLY MARGIN OF THE FLOW.



B. PAYNES CREEK BASALT RESTING UPON AGGLOMERATE NO. I, LEFT BANK OF SACRAMENTO RIVER, NEAR SECTION A-A.



AGGLOMERATE NO I, RESTING UPON THE UPPER SANDS, LEFT BANK OF SACRAMENTO RIVER, NEAR SECTION B-B.

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AGGLOMERATE NO. 1, VIEW SHOWING INTERBEDDED, SUBANGULAR BLOCKS OF LAVA AND THE GENERAL CHARACTER OF THE FORMATION, RIGHT BANK OF SACRAMENTO RIVER, OPPOSITE THE MOUTH OF SEVENMILE CREEK.

A. VIEW OF WEATHERED SURFACE OF AGGLOMERATE NO. I, SHOWING SUB-ANGULAR BLOCKS OF LAVA LEFT BY EROSION OF SOFTER MATERIAL, RIGHT BANK OF SACRAMENTO RIVER OPPOSITE THE MOUTH OF SEVENMILE CREEK.

B. VIEW OF WEATHERED SURFACE OF AGGLOMERATE NO. I, SHOWING SUB-ANGULAR BLOCKS OF LAVA LEFT BY EROSION OF SOFTER MATERIAL, RIGHT BANK OF SACRAMENTO RIVER OPPOSITE THE MOUTH OF SEVENMILE CREEK.

APPENDIX No. 2

REPORT OF BOARD OF ENGINEERS UPON IRON CANYON DAM SITES AND TYPE OF DAM

RED BLUFF, CALIFORNIA
MAY 7, 1920

DEPARTMENT OF THE INTERIOR,
UNITED STATES RECLAMATION SERVICE,
Denver, Colo., April 19, 1920.

From: Chief engineer.
To: Board of engineers.
Subject: Consideration of estimates and plans for dam in Iron Canyon for the Iron Canyon Reservoir.

1. The following board of engineers will meet in Red Bluff, Calif., on May 5 to consider the plans and estimates for the construction of a dam in Iron Canyon in connection with the Iron Canyon Reservoir:

D. C. Henny, consulting engineer, United States Reclamation Service.
A. J. Wiley, consulting engineer, United States Reclamation Service.
W. F. McClure, State Engineer of California.
Homer Hamlin, consulting engineer, United States Reclamation Service.
J. L. Savage, designing engineer, United States Reclamation Service.
H. J. Gault, engineer, United States Reclamation Service.

2. In 1914 consideration was given to the construction of a dam in Iron Canyon by the United States Reclamation Service in cooperation with the State of California, and a report of the investigations, including the report of the board of review appointed by the Secretary of the Interior, was published in November of that year. The board of review considered the construction of a dam in Iron Canyon just above the mouth of Paynes Creek and recommended further investigations.

3. In 1919 a cooperative contract was entered into between the Iron Canyon Project Association, the State of California, and the United States Reclamation Service, since which time further investigations have been made at the above-named site and also at sites farther downstream. The drilling which was done at the Paynes Creek site disclosed unsatisfactory foundation conditions, and geological reports by Consulting Engineer Homer Hamlin and Prof. A. C. Lawson, of the University of California, were not favorable.

4. It is desired that the board make careful study of the information available, including the published Cooperative Report of 1914, the recent reports of Consulting Engineer Homer Hamlin and Prof. A. C. Lawson, and the data secured from the investigations under the immediate charge of H. J. Gault during the past year, and that recommendations be made as to the type of dam which is considered best suited to the conditions, provided that any of the sites are deemed satisfactory to the board. In this connection the designing department of the Denver office has made studies of different types of dams which will be available for consideration.

5. A dam for storage purposes constructed in Iron Canyon will have an effect upon the navigability of the Sacramento River, but it is believed not necessary to go into that problem.

6. It is hoped that sufficient data have been secured to enable the board to definitely decide upon the best location and the best type of dam that can be constructed for the benefit of the Iron Canyon project, and the board should give consideration to all phases of the problem which are necessary to determine this question.

F. E. WEYMOUTH.

REPORT OF THE BOARD OF ENGINEERS.

To the United States Reclamation Service, the California State Department of Engineering, and the Iron Canyon Project Association.

GENTLEMEN: This board has convened at Red Bluff, Calif., in accordance with the request of April 19, 1920, of the chief engineer of the United States Reclamation Service, copy of which precedes this report.

Various plans of an Iron Canyon Dam were discussed in the printed report of October, 1914. These plans were all based on Location I, as shown on general location map, Exhibit B, following page 76. Subsequent boring investigations, carried out in accordance with recommendations made in 1914, revealed less favorable foundation conditions than had been assumed and further borings and drift work were deemed advisable to ascertain whether other dam sites in the canyon might be found where conditions are more satisfactory.

In accordance with suggestions made in reports of Mr. Hamlin,[1] a member of this board, and Prof. A. C. Lawson,[2] of the University of California, two lower dam sites have now been examined, marked Location II and Location III on Exhibit B, which have made possible an intelligent comparison and which have resulted in the selection of a dam site at Location III, about 3 miles below the original Location I. The geological conditions and the reasons for preferring Location III are explained in the following paragraphs.

The dam site at Location I is that proposed in the cooperative report. The one favorable feature of this site is the considerable amount of Agglomerate No. 1 in the abutments of the dam. This material, however, has a thickness of only 35 feet across the valley and in the river channel it has been entirely cut through into the soft sands and tuffs below, as shown on Exhibit D. At this site the agglomerate is harder than at any other point in Iron Canyon.

The unfavorable conditions are:

(*a*) Agglomerate No. 1 and the soft sands and tuffs below dip upstream, an attitude which favors percolation outward from beneath Agglomerate No. 1.

(*b*) The soft sands and tuffs beneath Agglomerate No. 1 are pervious, as shown by the fact that nearly all drill holes in this vicinity yielded artesian water.

(*c*) The narrow gorge cut through Agglomerate No. 1 extends some distance upstream from the dam site. Leakage will occur from the bottom of this gorge unless it is filled with impervious material which may prove to be an expensive and uncertain operation. Regarding this matter Prof. A. C. Lawson states: "Water entering these sands of the river trench under the head established by the reservoir would partly pass out under the surrounding country and escape at distant points, but would tend chiefly to escape by the shortest outlet which would be at the downstream toe of the dam. Judging by the incoherence of the sands, their coarse texture, their caving in the drill holes, the artesian flow from some of them and the strong undercutting of the river banks below low water, it seems probable that this escaping water at the lower toe of the dam, under high pressure, would acquire sufficient velocity to scour the sand at the points of escape. If this were so then a process making for the undermining of the dam and its ultimate failure would be inaugurated, since scouring would retreat upstream below the dam."

(*d*) Paynes Creek basalt is a very pervious formation, and is in general underlaid by a thin bed of porous stream gravel. To make this formation

[1] Appendix 1, page 41.

[2] Appendix 3, page 71.

water-tight a cut-off wall must be built, extending well down into Agglomerate No. 1, along the axis of the proposed spillway structure. In addition the spillway structure must be built on this pervious formation.

(e) Extensive erosion will occur in Paynes Creek Canyon if the spillway is built as located. Agglomerate No. 1 has been deeply trenched by Paynes Creek and nearly cut through in places. Below are the soft sands and tuffs some 100 feet in thickness, before any hard beds are reached. The overflow from the spillway, falling over the west wall of Paynes Creek Canyon, will soon cut through Agglomerate No. 1 and undermine it and the basalt above.

When all the adverse conditions at this site are considered it is not believed that a dam such as proposed is practicable. Obviously an earth or masonry dam would also be impracticable.

Prof. Lawson recommended tests at a dam site here designated Location II, at a point where the hard Agglomerate No. 2 crosses Sacramento River, forming a riffle or small rapids. Here drill holes show Agglomerate No. 2 to be from 9 to 28 feet thick and that it rests upon pervious sands and tuffs of unknown thickness, but at least 100 feet thick. The pervious sands and tuffs which rise from beneath Agglomerate No. 1 at Location I would here form the abutments of the proposed dam. It is believed that Agglomerate No. 2 is not thick enough for the foundations of a masonry dam and that the sands and tuffs both beneath and above Agglomerate No. 2 are pervious. This dam site can not be recommended.

At Location III Agglomerate No. 1 is about 140 feet thick. The river canyon has been cut down into it some 30 feet, leaving about 110 feet in thickness above the pervious sands and tuffs on which it rests. This is a sufficient thickness to withstand the upward hydraulic pressure from a full reservoir, as planned.

Here Agglomerate No. 1 is not as hard as at Location I, but its bearing power is sufficient to withstand the pressures from a properly designed masonry dam. The dip of Agglomerate No. 1 and the formations both above and below it is downstream, hence the removal of material from beneath Agglomerate No. 1 by percolating water is not possible.

If cut-off walls in the sands and tuffs which rest upon Agglomerate No. 1 are found necessary they can be constructed in the dry above high-water level in the river. Here the canyon is wide enough to permit the construction of flood-control gates, siphon spillways, and supplementary overflow spillways.

In anticipation of the selection of Location III the Denver office of the United States Reclamation Service has made tentative plans and estimates of two types of dam, viz, gravity-section concrete and a combination of solid masonry for the high portion of the dam with buttress and slab construction for the sides. In addition for comparative purposes the previous estimate of a rock-fill earth-faced type of dam at Location I with masonry spillway and power-plant features has been revised by adding a deep cut-off wall in porous lava under the spillway and by increasing unit prices to correspond with present market conditions.

The comparison stands as follows:

Location.	Type.	Date.	Available reservoir capacity, acre-feet.	Estimated cost, including right of way and Bend Embankment.	Cost per acre-foot.
I	Earth faced rock fill	1914	603,000	$10,385,250	$17.20
I	.....do	1920	603,000	16,089,000	26.70
III	Gravity concrete	1920	640,000	17,977,000	28.10
III	Combination reinforced and gravity concrete	1920	640,000	17,385,000	27.20

The above estimates are not strictly comparable even on the basis of acre-foot cost. The designs for Location I provide for only 190,000 second-feet spillway capacity at assumed high water, the remainder of the flood peak being figured as absorbed in surplus reservoir capacity over that required for irrigation. This entire surplus capacity and even more is now needed for irrigation alone by reason of irrigation rights on the river initiated and largely matured since 1914. This would necessitate at Location I a greatly increased expenditure for spillway.

On the other hand the first two estimates include the cost of a 70,000-horsepower installation while the last two make provision for only 60,000-horsepower. The reduction in cost occasioned by this last difference is, however, likely to be smaller than the addition which would have to be made for spillway purposes, so that it is likely that no great difference would exist in the acre-foot cost at either location and that this cost will be close to $28, barring in either case entirely unforeseen foundation and flood contingencies.

In regard to the amount of storage required it should be stated that a revised study has been made by Mr. Gault, who bases his study on a net duty on the land of 2.75 feet, a total canal loss of one-third with a consequent diversion duty of 4.125 feet, as compared with 3 feet, which was used in the 1914 report. Mr. Gault further deviates from the older report in considering it necessary to pass the entire flow through the reservoir when the flow is 6,000 second-feet or less, during May to August, inclusive; 5,000 second-feet or less in April and September; and 4,000 second-feet or less in the remainder of the year, the limit in the 1914 report being 4,750 second-feet. The reason for this deviation is the large expansion of pumping irrigation in the Sacramento Valley since 1914, which has practically absorbed the entire normal low-water flow above the mouth of the Feather River, the rights so far matured aggregating between 5,500 and 6,000 second-feet. This leaves little, if any, water for navigation or for claims of riparian owners. On the other hand the project itself may produce some return flow.

On the above basis Mr. Gault figures that with a reservoir all devoted to irrigation and holding 640,000 acre-feet, shortages would have been as per the following table:

Per cent of deficiency.

1898	7.9
1899	3.4
1900	1.1
1901	.6
1918	13.0
1919	1.1
1920 (up to Oct. 1)	16.4

In the above, no consideration was had of the Anderson-Cottonwood district appropriation just above the reservoir of 400 second-feet which is in process of maturing, except that since 1918 a small portion of the above was actually diverted. The ultimate appropriation may be cut down to about 300 second-feet if the Iron Canyon project should acquire with the district lands necessary for the reservoir the water appurtenant thereto. This diversion will slightly increase the above shortages, possibly about 2 per cent.

This board has taken cognizance of the above facts merely to consider the general correctness of the size of reservoir to be provided. Further study might suggest a change; but if so, it is not likely to be of sufficient importance to affect the main object of this report.

Location III, being geologically shown to be the most desirable one, and similarity of tentative estimates indicating no great superiority as to cost of the rejected upper Location I, has been made the basis for further study of dam design. The longitudinal section along the dam center line together with the plan of the dam is shown in Exhibit L, following page 76.

The first question which arises is the character of material available for construction. Local material consists of agglomerate, soft sandstone, tuff, and cemented gravel. At about 4 miles distance excellent concrete aggregate may be had in large quantities. Hard riprapping rock is not available short of Paynes Creek, about 3 miles upstream, or may be had from quarries on the main Southern Pacific Railway 40 miles or more north of Red Bluff.

The entire length of the dam is about 1 mile, all but 1,700 feet being 70 feet or less in height. The channel section would have a length of 800 feet and have a height of 170 feet and 900 feet length of dam located on the canyon slopes would have a height ranging from 170 to 70 feet.

The spillway flow to be provided for is estimated at 350,000 second-feet. It is possible to release this flow over a long spillway on the west shoulder of the canyon at some distance from the channel section. The down flow of this mass of water on its return to the river would take place through existing gulches and channels which might be enlarged for the purpose, but which by reason of their length to the river and the friability of the local formation would be extremely expensive to protect from erosion. We believe that only an emergency spillway of relatively small capacity is permissible on the west shoulder of the river canyon.

A spillway channel on either one or both of the canyon sides, with short return channel to the river, would involve very difficult and expensive construction features. The discharge would have to be turned at right angles toward the channel under high velocity and the sandstone and tuff formation through which this channel would have to be largely constructed would require extraordinary protection against erosion.

The problem of spillway discharge becomes relatively simple through a solid concrete channel section of the dam and similarly such section would afford the most economical means of power water discharge. Such section would also inspire the greatest confidence in view of the presence of a large population in the valley below the dam.

The principal reason for the selection of Location III was explained in previous paragraphs to be the existence of a mass of agglomerate 110 feet in thickness below the river channel at the dam site. This material where exposed at the surface is a natural concrete which is probably water-tight and has considerable hardness and great bearing power, in every way satisfactory as a foundation for a high concrete dam. The records of borings, however, are not nearly so favorable. The fine binding material in the interior of the mass is rather soft, so that but a small percentage of core was produced. In a drift in the east abutment of the dam also the material becomes rather soft away from air exposure.

A bearing test was made by Mr. Gault indicating for the softest part of the material that no yielding resulted under a pressure of approximately 40 tons per square foot, the test surfaces being 1 square foot and the material being dry. To what extent in such test the side support of the material under stress aided in supporting the load is uncertain as is also the softening effect which water might produce. We believe, however, that this agglomerate will furnish a safe foundation provided the maximum pressures do not exceed 10 tons, which

is close to the limiting stress in the Denver design, of which the maximum section is shown in Exhibit M.

In this section the back slope has been taken as 1:1, or flatter than an ordinary gravity section as a result of gate and siphon spillway design. The section is large enough to provide against one-third full pressure uplift near the heel, diminishing to zero near the toe.

The general agglomerate mass is probably reasonably water-tight even where it may lack hardness. Nevertheless, a cut-off trench of 40 or 50 feet into this material at the heel may be regarded as necessary. The material seems to be remarkably free from seams, but grouting below the plane of cut-off is desirable as a precautionary measure, together with providing drains back of the cut-off, these drains to be confined in depth to the agglomerate and on no account to penetrate to the underlying sandstone and tuff.

With such provisions it is not likely that any material uplift under the foundation will develop, and the provision to the extent explained above seems entirely sufficient. There is, however, some doubt as to whether the base of the dam should not be spread in an upstream direction with steel reinforcement reaching into the main base of the dam to take up shear and tension, to lessen the abruptness of the change from no load to full load, and to keep the maximum load within the 10-ton limit.

The material in the hillsides continues to be agglomerate for a height of about 30 feet, above which level occur tuffs and sandstones, which in large part seem less desirable as a foundation for a masonry dam. The estimates prepared in Denver assume concrete masonry construction from end to end. It seems to us desirable that designs be also made on the basis of earth-dam construction, such construction to commence at points on either side of the masonry section, where an abutment wall could be feasibly founded on agglomerate by deep excavation, but where the height of the dam above the surface has become diminished to from 80 to 70 feet. This is suggested largely by foundation conditions, although it may also lead to lesser cost.

In regard to spillway and power outlets, the solution offered by the Denver office can not at present be improved upon in the limited time available to this board. It should be stated, however, that we believe the apron protection below the dam may have to be extended to insure the standing wave occurring on the apron. Possibly an increase in height of upstep may be required to minimize the distance from dam to wave. It may also be wise to consider a concrete upstream apron under the earth blanket, reaching possibly 100 feet upstream on bottom and canyon sides to insure against water passing down between earth apron and dam face.

The safety of the dam as designed, or as it may be redesigned, depends not only on the immediate foundation but also on the conditions of underflow in the sandstone and tuff beds below the agglomerate. To satisfy ourselves as to this crucial feature we have studied boring records and examined these beds where they rise in the exposed canyon sides upstream from the dam site, as shown on Exhibit D.

The artesian flow from various bore holes indicates that the sandstone will permit slow flow of water. The most dangerous places in such cases are usually the planes of contact between different beds. Contact wherever examined seems to be perfect. The flow proceeds probably from the coarser layers which may not be extensive although pockets may occur with great frequency.

We believe that danger from a rapid flow establishing itself along certain lines under the dam, such as might begin carrying material and ultimately leading to the undermining of the dam, would be very serious to the extent of

causing condemnation of the dam site if it were not for the fact that these sandstone layers below the dam are overlaid by a heavy capping of reasonably dense agglomerate dipping in a downstream direction. This agglomerate layer, 140 feet thick where not eroded by the river and with a minimum thickness next the dam of 110 feet, is so far as known remarkably free of seams. No springs have been discovered on the surface of this layer. The weight of this mass is sufficient, as previously stated, even where not overlaid, as in the sides of higher strata, to resist the full upward pressure which might be caused by underflow. Should any seam exist and water rise through it, it is not readily conceivable that any sand would be discharged through it, and if any sand movement from below should gain headway, it seems certain that the seam would become promptly clogged and choke any further upward movement of sand.

The possible occurrence of seams in this material has been especially a subject of study on the part of Mr. Hamlin, who holds that no fear in that regard need be entertained.

We conclude, therefore, that while conditions for a dam at the best site available are far from ideal a safe dam can be constructed at this point, Location III, but it must be admitted that the item of contingencies to guard against all dangers which may become apparent upon opening up the foundation may be greater than usual and that the total for this dam, including also overhead expenses, estimated at 25 per cent, may be exceeded.

Your instructions did not require us to extend this study to the problem of project feasibility. We have nevertheless given some thought to this matter in connection with further action contemplated by the Iron Canyon Project Association.

So far as the dam and reservoir are concerned the present estimate stands about as follows:

Total cost, including 60,000 horsepower development	$17,977,000.00
Credit to irrigation on account of power	7,500,000.00
Net charge for reservoir to irrigation	10,477,000.00
Available capacity, 640,000 acre-feet, net cost per acre-foot available	$16.40
Irrigable area, 225,000 acres, net cost per acre	46.60

As to the total acre cost we have used certain revised estimates made by Mr. Gault of the main canal and distribution features, indicating that the former may cost about $50 per acre and the latter $37, resulting in a total cost exceeding $130 per acre. It is possible that a greater credit may be secured for power, against which there is also the possibility that requirements as to unquestioned safety of the dam may compel large additional expenditures over those estimated.

The project is one which can become possible only through full support of the great majority of landowners, and it is well that they have a general knowledge of possible cost to guide them in their further efforts, for which purpose such figures as are now in our possession are above presented in this report.

Comparing this cost with the cost of plan A–4 in the 1914 report, with smaller total storage, if the cost of that plan had been reduced by probable power value only and had not received credit for flood control, for which under the changed water-right conditions the reservoir contains no reservation, the acre cost as then estimated would have been $65. Additional diversion as

now figured, together with a practically doubled cost of labor and materials, would, roughly, result in about the same acre cost as is now figured in connection with a changed dam location.

D. C. HENNY.
A. J. WILEY.
HOMER HAMLIN.
W. F. MCCLURE.
J. L. SAVAGE.
H. J. GAULT.

RED BLUFF, CALIF., *May 7, 1920.*

APPENDIX No. 3

REPORT OF PROFESSOR A. C. LAWSON UPON GEOLOGY OF IRON CANYON

BERKELEY, CALIFORNIA
AUGUST 31, 1919

REPORT ON GEOLOGY OF IRON CANYON.

Mr. W. F. McCLURE,

State Engineer, Sacramento, Calif.

SIR: There are two possible dam sites in Iron Canyon to which my attention has been drawn: One immediately above the mouth of Paynes Creek and the other just below the bend about a mile downstream from Paynes Creek. I have examined both of these under the guidance of Engineer H. J. Gault, and beg to advise you regarding the geological conditions affecting the security of a dam at each place, as follows:

The general features of Iron Canyon are known from the Report on Iron Canyon Project, issued by the United States Reclamation Service October, 1914, and, as my observations are supplementary to the information contained therein, extended descriptions of the topography, general geology, and physical features of the canyon become unnecessary. I shall therefore address myself immediately to the question of the relative merits of the two sites from a geological point of view.

SITE ABOVE PAYNES CREEK.

This site is the one shown on Plate XXV, page 100, of the report just referred to. Here the geological section on the north side of the Sacramento River comprises in descending order:

1. Basaltic lava of variable thickness, but notably thinner on the canyon walls than at points back from the river. Maximum known thickness 81 feet near drill hole D–1.

2. Loose stream gravel ranging in thickness from a few inches to a few feet; also probably thicker a short distance back from the river than shown on the cliffs of the canyon.

3. Agglomerate ranging from 40 to 50 feet above low water to a few feet below low water of the river.

4. Tuffs of indefinite thickness below low water, but appearing above low water below Paynes Creek.

5. Volcanic sand intercalated with the tuff at various horizons, as revealed in the records of borings.

On the south side of the river neither of the formations numbered 1 and 2 above is present. The agglomerate occupies the sides of the canyon from low water to a point above the crest of the proposed dam. Below the agglomerate tuff and sand are present as on the south side.

On the north side of the river the upper part of the dam rises above the top of the basaltic lava, and the whole of the spillway is above the same formation. Behind the spillway and dam the lava forms the floor of the reservoir for a considerable acreage.

The lava is traversed by innumerable cracks, some of them open crevasses, and it is besides this honeycombed with cavernous openings, which render the formation as a whole a veritable sieve. There would be an enormous leakage through the lava unless an impervious curtain were inserted in it extending from the lower abutment of the dam the whole length of the spillway and perhaps beyond the east end of the latter.

The loose stream gravel immediately below the lava is the gravel of the old channel into which the lava flowed, and it is freely permeable. Water from a reservoir entering this gravel on its upstream side or coming to it from the overlying fissured and cavernous lava would escape in important quantities with sapping effects. The impervious curtain necessary to render the lava a permissible foundation for a dam and spillway would therefore have to be extended down through this gravel into the underlying agglomerate. Protection against this very serious leakage does not appear to have been considered in the report of the United States Reclamation Service of October, 1914. The expense of such protection would be a heavy item in the total cost of the proposed structure.

The agglomerate is a satisfactory rock for a dam foundation. It has sufficient strength, and, although not homogeneous, is of low permeability. The rate of transmission of water through it would be so slow that there would be practically no leakage. It is not traversed by cracks or joints of importance, nor are there any cavernous openings in it.

The tuff underlying the agglomerate is also a satisfactory rock for a dam foundation. It is a fairly coherent, homogeneous, stratified rock of light color, and fine texture, composed of cemented volcanic ashes. It is sufficiently strong for the purpose of support and has so fine a pore space that the rate of transmission of water through it would be very slow and the leakage even under high pressures practically negligible.

The volcanic sand is known chiefly from the records of the drilling operations, and, from the point of view of leakage, must be a source of concern to those charged with the responsibility of selecting a site for the dam. This volcanic sand is incoherent, medium coarse to gravelly, and freely permeable by water with a relatively high rate of transmission.

This sand occurs at various horizons, interstratified with the tuff, and beds of it occur near the top of the tuff at its contact with the agglomerate. This contact at the dam site is but a short distance below the low water of the river, and the stream trench of the Sacramento has cut sharply through it, thus bringing the sands and gravels of the river bottom in immediate contact with the volcanic sands of the tuff. These sands will undoubtedly supply an avenue of leakage from the reservoir. The engineers have proposed, in order to prevent serious leakage under the dam, to fill the stream trench with clay. This would, however, simply be burying a pipe of gravel and sand, and it is further proposed to intercept the flow of water in this pipe by a cut-off near the up-stream toe of the dam. If the stream gravels were confined in a trench of impermeable rock this scheme would work admirably. But in the case before us the stream gravels are in immediate contact with the freely permeable volcanic sands and gravels in the tuff, which can not be cut off; so that the escaping water would readily short-circuit around the cut-off, and the latter would be of no effect.

The water entering these sands of the river trench under the head established by the reservoir would partly pass out under the surrounding country and escape at distant points, but would tend chiefly to escape by the shortest outlet which would be at the downstream toe of the dam. Judging by the incoherence of the sands, their coarse texture, their caving in the drill holes, the artesian flow from some of them, and the strong undercutting of the river banks below low water, it seems probable that this escaping water at the lower toe of the dam, under high pressure, would acquire sufficient velocity to scour the sand at the points of escape. If this were so, then a process making for the undermining of the dam and its ultimate failure would be inaugurated, since the scouring would retreat upstream below the dam.

From the considerations set forth it appears to me that neither the rocks of the upper part of the section nor those below low water are suitable for the construction of a large dam. The extremely leaky character of the basaltic lava and the immediately underlying gravels may perhaps be cured at great expense, but I have very grave doubts of the possibility of preventing large and dangerous leakage below the dam, owing to the difficulty, if not the impossibility, of intercepting the flow of water from the reservoir into and through the volcanic sands and gravels of the foundation.

SITE AT THE BEND ONE MILE BELOW PAYNES CREEK.

At this locality the geological conditions affecting the security of a dam are much more favorable. The prevailing formation is a fairly homogenous fine-textured, stratified tuff composed of cemented volcanic ashes. Interstratified with this tuff, close to low-water level, is a bed of agglomerate about 30 or 40 feet thick. This is not the same agglomerate as that at the mouth of Paynes Creek, but another stratum, at a lower geological horizon. This tuff and agglomerate dip downstream at an angle of about 3 degrees, and the agglomerate forms the sides of the stream trench for about 1,500 feet, and probably forms the bottom of the trench for a distance of 1,000 feet. A firm, impervious basement of agglomerate is thus supplied upon which a dam, in this case presumably a concrete dam, may be erected. Above the agglomerate, on the east side of the river, vertical cliffs of stratified tuff rise to above the 400-foot contour. On the west side of the canyon the walls are not so precipitous, but expose the same formations as are found on the east side; and above the tuff on this side, at the top of the canyon walls, is an agglomerate—the same formation as that which comes to the water level at Paynes Creek. On the cliff face to the east there appear to be no sand layers. The cliff is, however, too steep to be accessible for detailed examination. To the west the slope is covered by soil in large part so that the presence of sand could be determined only by boring. My opinion, based on an inspection of the east cliff from below, is that there are no sand layers that would scour at the point of escape water and that the rate of transmission of water through tuffs above the agglomerate would be so slow as to render them perfectly safe. I should be very loath to have this opinion accepted, however, without the verification of engineering examination.

The only two borings in this vicinity are C–1 and C–2 of the report of the United States Reclamation Service. C–1 is at least 500 feet north of the extreme northern limit of the dam site and is wholly below the agglomerate, which here has been removed by erosion. C–2 shows 16 feet of agglomerate resting on 12 feet of tuff, which cores well, and, below this, black sand. The southerly dip of the strata insures the condition that as we pass downstream from C–2 the agglomerate will increase in thickness and the tuff and sand will both get deeper.

The trench in which the stream flows at low water is at this locality relatively wide and shallow. The water which might flow into the underlying black sand under reservoir head probably could not communicate with the stream gravel and sand in the trench, and, the latter being shallow, might be thoroughly cleaned out for purposes of effective cut-off. This water, moreover, could not appear at the downstream toe of the dam, but would be diffused through the surrounding country; and, if it escaped at all, the points of escape would be remote and take the form of ordinary springs.

In short there are no serious objections from a geological point of view to the construction of a high concrete dam on the basement of agglomerate so clearly exposed at this locality. Both the foundation of such a dam and the abutments appear to be practically water-tight.

I therefore recommend that engineering investigation be directed to this si and that a series of borings be put down, none of which needs to exceed 1 feet below low water to test the conclusions based upon a geological examin tion of the surface. With the data at present available this site is certain much to be preferred to the one just above Paynes Creek.

Respectfully submitted.

A. C. LAWSON.

BERKELEY, CALIF., *August 21, 1919.*

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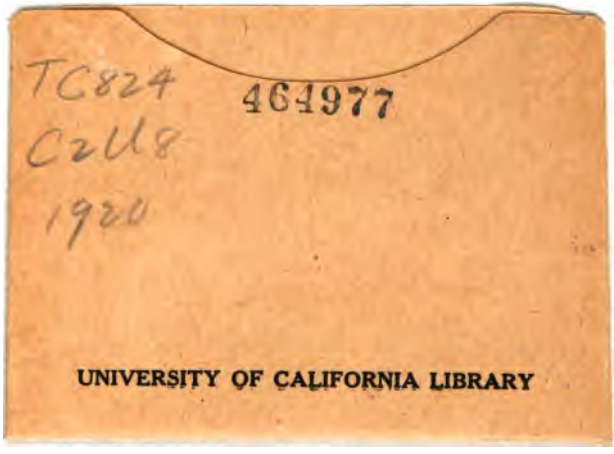
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